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Preface

> *"We've arranged a global civilization in which most crucial elements profoundly depend on science and technology. We have also arranged things so that almost no one understands science and technology. This is a prescription for disaster. We might get away with it for a while, but sooner or later this combustible mixture of ignorance and power is going to blow up in our faces."*
>
> *— Carl Sagan*

Conference epiSTEME 8 is a biennial international event to review research in science, technology and mathematics education (STME) hosted by the Homi Bhabha Centre for Science Education (HBCSE), a National Centre of the Tata Institute of Fundamental Research (TIFR). Initiated in 2004, the primary aim of the conference is to nurture and promote scholarship in STME research, which is still nascent in India. The conference, by bringing together leading researchers from across the globe, has been playing an important role in strengthening the field in this country. It is unique in its addressal of multidisciplinary issues pertaining to the teaching and learning of science, technology and mathematics. Arguably epiSTEME is the flagship conference in STME research in India, an area that holds great potential for the country owing to its huge, aspiring student and teacher population. Details of the past seven editions of the conference are available at http://www.hbcse.tifr.res.in/episteme.

Quality science education to a larger populace is integral to our economic and societal progress. To enable this challenging task, it is important that we deconstruct the core issues at the intersection of content, cognition and culture relevant to STME education. Conference epiSTEME 8 will have its focus centred around some of these core issues. In particular the conference aims to generate discussion around topics on important scientific practices such as modelling in STME, alternative conceptions in various disciplines, role of language in STME, insights from cognitive science and sociocultural studies relevant to STME, among others. The premise of the conference is based on the conception of science as a liberal art. A panel discussion on the same titled *'Towards a pedagogy of science as a liberal art'* will also be held as part of the conference.

The four different strands and various sub-themes around which the review talks, papers and poster presentations of the conference fall, are:

Strand 1: Historical, Philosophical and Socio-cultural Studies of STME: Implications for Education
- Theme 1: History and Philosophy of STME
- Theme 2: Socio-cultural and gender issues in STME
- Theme 3: Science and Technology Studies
- Theme 4: Science as a Liberal Arts

Strand 2: Cognitive and Affective Studies of STME
- Theme 1: Modelling in Science Education
- Theme 2: Knowledge representation
- Theme 3: Affective aspects of learning
- Theme 4: Problem solving, learning and reasoning
- Theme 5: Visuo-spatial thinking

Strand 3. Language, Pedagogy and Curriculum in STME
- Theme 1: Language and learning
- Theme 2: New Media, Role of ICT in teaching-learning
- Theme 3: Classroom interaction and discourse

Preface

- Theme 4: Assessment and evaluation
- Theme 5: Professional development of teachers
- Theme 6: Educational initiatives and innovations

Strand 4. Discipline-based Education Research with Emphasis on Undergraduate Science Education
- Theme 1: Astronomy Education Research
- Theme 2: Biology/Life Science Education Research
- Theme 3: Chemistry Education Research
- Theme 4: Physics Education Research

There are nine review talks from leading scholars around the globe on some of the key themes mentioned under the above strands. In addition researchers from across the world will be presenting papers and posters. In total epiSTEME 8 received around 110 submissions from 13 different countries (Australia, Brazil, Cyprus, Germany, India, Nepal, Rwanda, Somalia, South Africa, Switzerland, Uganda, United Kingdom and United States). All submissions were sent to at least two reviewers working in related areas for blind reviews. The list of reviewers is included in the proceedings. We thank all the reviewers for their scholarly remarks which we hope helped the authors and significantly improved the quality of the manuscripts. We accepted around 60 papers, out of which authors of 51 papers registered for the conference. Of these 30 papers will be presented in the oral mode and the rest 21 in the poster mode.

We express our sincere gratitude to all members of HBCSE for their help and cooperation at various phases of the conference organisation. In particular we thank Prof. K. Subramaniam and Prof. Sugra Chunawala for their support, guidance and encouragement. We thank the convenors of the previous two editions of the conference, Prof. Savita Ladage and Prof. Sanjay Chandrasekharan for their guidance throughout. We greatly appreciate the contribution from all the members of the academic committee and local organisation committee for the conference. The head of administration Shri Abhyankar and head of accounts Shri V.P. Raul deserve special mention for their help towards planning and execution of various crucial organisational aspects of the conference. We thank Manoj Nair for his help in setting up the conference website, paper submission portal and the payment gateway.

We specially thank Charudatta Navare, Deborah Dutta, and Deepika Bansal for helping us with editing works. We thank Adithi Muralidhar for her guidance with the publication of these proceedings.

— K.K. Mashood, Tathagata Sengupta, Chaitanya Ursekar,
Harita Raval and Santanu Dutta
January 2020

Contents

Contents

Contents

Contents

Contents

HALF A CENTURY OF RESEARCH ON ALTERNATIVE CONCEPTIONS/MISCONCEPTIONS IN SCIENCE EDUCATION: WHAT HAS CHANGED?

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Studying students understandings of science phenomena is fascinating. A key element is unravelling ways of sense making as everyday experiences, language, overheard conversations are intertwined with what the teacher is saying. The teacher attempts to guide their learners to more scientific congruent ideas, the learner detours and goes through alleys slowly changing and every now and then producing what the teacher delights in hearing. The process is not quick enough for the teacher and convoluted for the learner. Is this a surprise? Once a learner sees ideas through the 'lens of science', some say it is hard to revert back, one has gone the threshold portal. But progressing through 'the scientific lens' is not trivial, after all, much is counterintuitive. What is reassuring for researchers is that there are identifiable, consistent and enduring ideas and pathways which form the cornerstones of alternative conceptions or misconceptions research. The solution is then to find ways through which these can be addressed. Overtime, experiments, technology, simulations and a range of tools have been identified and used. The successful interventions have been reported and some translated into systematic practice underpinning curricula. In this talk I will summarise the field, the contributions of my research team, from multimedia, Veritasium YouTube Channel to concept tools. A key finding which is often not reported is how students develop over their years of physics study, what are their trajectories of changing conceptions. If they don't 'overcome' misconceptions in first year, can they 'overcome' them later on if not explicitly taught? We also offer a few different way of using and thinking about alternative conceptions, threshold concepts from the 'troublesome knowledge' tradition and LCT from linguistics.

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Muller, D. A., Sharma, M. D. and Reimann, P. (2008) Raising cognitive load with linear multimedia to promote conceptual change. *Science Education* **92(2)**, 278-296.

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THE ATTRACTIVENESS OF A TOPIC APPROACH TO IMPROVING PEDAGOGICAL CONTENT KNOWLEDGE OF TEACHERS – LESSONS FROM RESEARCH IN SOUTH AFRICA

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It is thirty-four years since Lee Shulman drew the education research community's attention to the importance of explicit inclusion of content knowledge in both pre and in-service teacher education. To address this gap in our understanding of teacher knowledge he introduced the idea of pedagogical content knowledge (PCK) which was embraced with enthusiasm, particularly in the science education community. However, diverse interpretations about the nature of PCK and its relation to content knowledge followed. Since then, consensus has been sought to reach a unified understanding of the PCK construct through intensive discussions by researchers at two PCK summits held in 2012 and 2016, most recently resulting in a refined consensus model of PCK, published in 2019. PCK is theorised as powerful knowledge possessed by teachers, which enables them to transform content into a form that is easily understood by their students. It is tacit knowledge, which is thought to be acquired largely through experience. This talk provides a review of PCK models through the years culminating in a consideration of the power of conceptualising PCK at the topic level, known as Topic Specific PCK, or TSPCK. Consideration of PCK at the topic level has allowed researchers to look more closely at the some of the root causes of poor performance of South African students in science, which has been broadly blamed on teachers' poor content knowledge. The research described in this talk is driven by an attempt to improve both novice and experienced teachers' PCK through topic specific interventions. To measure the success of these interventions, validated pairs of instruments measuring CK and TSPCK have been designed to establish baseline knowledge of teachers in eight topics, two in physics and five in chemistry. The interventions have been very effective, improving teachers' TSPCK as well as their content knowledge. There is also evidence that the interventions enhance the teachers' ability to apply the tools used in the intervention to topics, which were not the subject of the interventions, now known as signature interventions. Further research has shown that pre-service teachers who have been exposed to signature interventions during their teacher education after qualification perform better than those who have not. The TSPCK research group at Wits University has produced 22 refereed articles and 35 masters and doctoral theses collecting evidence on topic specific PCK, the construct used as a lens to capture and measure PCK and investigate the effectiveness of interventions. The talk will also provide samples of data giving insights to the effectiveness of the approaches used in the research as well as the various methods of analysis used. The talk will conclude by looking at international collaborations currently under way and plans for future research.

Reference Papers:

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PERSPECTIVES ON CONCEPTUAL CHANGE AND ITS NEXUS WITH IDENTITY

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After a brief overview of the perspectives on Conceptual Change and about the history of this multi-disciplinary research field, the talk will explore a novel, yet theoretically and methodologically thorny, research issue: the intersection between the conceptual change and identity.

Conceptual change is traditionally thought of as an individual cognitive phenomenon whilst identity development has usually been conceived of as a social construct involving the relationship between groups and individuals. This aspect raises important questions for how these constructs can be articulated in such a way as to be mutually illuminating.

The talk will illustrate and discuss significant approaches to forging productive connections between the research agendas of conceptual change and identity development. To pursue this goal the approaches will be reviewed and compared through a framework that allows for pointing out both the divergences and their common theoretical structure. This structure is argued to be potentially fruitful for orienting a program of further rigorous investigations of the nexus between conceptual change and identity.

Acknowledgment

The talk is based on the reflections and analyses that Tamer Amin, Mariana Levin and I carried out for edited volume entitled “Converging Perspectives on Conceptual Change: Mapping an Emerging Paradigm in the Learning Sciences” (Eds. T. Amin & O. Levrini, Routledge, 2018).

LOGIC IN SCHOOL MATHEMATICS: THE OUTSIDER AT THE WINDOW

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The infinite we shall do right away. The finite may take a little longer.
— Stanislaw Ulam

Ulam might as well have been talking of the school mathematics curriculum, which inexorably leads the student to Calculus at its end. Infinite sets (like the set of natural numbers and integers) and infinite objects (like real numbers, rays) are pervasive in mathematics from middle school onwards, though in an intuitive rather than axiomatic form. *Finite mathematics* makes short, almost apologetic, appearances. A syllabus unit titled *Mathematical reasoning* is often included. Typically it is about propositional logic, and students are trained in verifying if a given boolean formula is a tautology. Since this part is allotted only about 4% of the teaching time in the whole year (of Class XI in India) with 2% weightage in the final examination, it is not taken very seriously by all concerned, who have $\sin \alpha + \sin \beta$, conic sections, the binomial theorem etc. to worry about, and they are surely more difficult. Mathematical modelling is largely absent from school syllabi.

Now, with the realisation that discrete mathematics lies at the foundation of computation, a demand for it is heard, with logic included in the package. *Computational thinking* is the new paradigm, but though this is about enumeration, repetitive patterns and discrete modelling, it is not (yet) considered to be a part of the mathematics curriculum.

Yet, all through school, students learn deductive procedures in equational theories and employ deliberate means of reasoning in algebra and geometry. Interestingly, the little logic introduced tends to be propositional logic rather than the logic of quantification, while the latter is the form of logic unconsciously used by the student in mathematics. Leaving this implicit has serious drawbacks, as for example evidenced by students asked to solve the equation: $1/(x-1) = x/(x-1)$.

Logic remains the outsider in the mathematics classroom, not far away but gazing in from the window, watching these plays.

Logic is not only about deductive reasoning. Logic is also a conscious use of formal language, understanding truth relative to models, figuring out consequence, relating assertions to algorithms that check those assertions, and studying limits to reasoning.

In this talk, we observe that all these are already implicit, scattered here and there, in school mathematics, and suggest that there is reason to explicate these, for curricular and pedagogic purposes, as well as to enrich teacher knowledge. We discuss how granting first class citizenship to logic in school mathematics can help with computational thinking as well.

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2. Viviane Durand-Guerrier, Logic and mathematical reasoning from a didactical point of view, Thematic Group 4, European research in mathematics education III. available from http://www.mathematik.unitdortmund.de/~erme/CERME3/Groups/TG4/TG4_Guerrier_cerme3.pdf

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5. Susanna S Epp, Logic and discrete mathematics in the schools, In *Discrete Mathematics in the Schools, DIMACS Series in Discrete Mathematics and Theoretical Computer Science*, vol. 36.

6. Joseph G. Rosenstein, D. S. Franzblau, F. S. Roberts, Eds. *Providence*, RI: AMS Publications, 1997, 75-83.

SCHOOL SCIENCE, EQUALITY AND FAIRNESS

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Throughout the world science and technology, or STEM as it has come to be known, are seen as crucial instruments in ensuring national prosperity. At the same time there is a consciousness that the products of science and technology should be directed towards the public good, hence the policy coda of Responsible Research & Innovation (RRI) which underpins funding of S&T research and education in the European Union. This linking of social issues to science - socio-scientific issues in educational terms - has always faced epistemological problems. These problems include the focus on the Mertonian norms of science as objective and disinterested, the prevalence of empiricist and positivistic methods in science practise, and the ideological sway of Hume's naturalistic fallacy or the 'is-ought' dichotomy. Indeed some educationalists have argued effectively that science as a discipline has a distinctive space in the school curriculum with a unique set of concepts and principles (Hirst & Peters, 2011)

I shall argue that interpretations of Enlightenment rationality have hampered the development of socio-scientific issues and the gearing of science education to social justice. Rather than argue for a bolt-on connection between science and society, underpinning so-called Vision I and Vision II approaches (Roberts & Bybee, 2014) I claim that the practise of science can only flourish through an understanding of social justice at its core. Prevalent neoliberal formulations of science and society mean that S&T research and development skims over deep and structural injustices.

There are two theoretical positions I shall draw on, with examples, to argue that science practise and learning cannot be decoupled from questions of social justice. Critical Realist metatheory (Collier, 1994; Levinson, 2018a) has the reality of human emancipation at its core. Taking the world as ontologically real (the intransitive dimension) and epistemologically relativist (the transitive dimension) – what is is not the same as what is known - Critical Realism considers natural phenomena as open systems to be investigated. It finds an approach to science practise between naïve realism and empiricism, buttressed by an appeal to judgemental rationality. Theories about the nature of reality can be judged according to valid criteria of truth. At the same time stratification and emergence can generate explanations through causal mechanisms in diverse disciplines from the physico-chemical to the socio-economic. The explanation of events is thus inter-disciplinary.

Secondly Levinas's ethics of the refusal of subjectivity allows us to recognise difference and diversity, that Nature can be studied from a different perspective from the dominant subjective 'I', a hangover from

Enlightenment rationality. From this perspective I create a picture of the non-presumptive and knowledgeable science teacher (Levinson, 2018b). If social justice is intrinsic to science education then it must also be at the heart of pedagogy. Finally I draw on the 'story' demonstrating how the personal and political are interwoven in understanding scientific ideas through interlocking narratives (Levinson, 2009). My conclusion is that science teaching should focus on explaining events in an interdisciplinary manner which not only couples science to the social but also deepens understanding of core scientific concepts.

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INDUCTING CHILDREN IN THE EPISTEMOLOGY OF MODELING

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A central aim of education is to help learners understand how knowledge is articulated in the disciplines. Contemporary perspectives in the learning sciences emphasize that knowing emerges from interactions among discipline-specific practices that generate an ensemble of concepts, along with ways of thinking about their significance in light of imagined and experienced critique. To create conditions that support this kind of learning, I work with teachers to design learning ecologies in which children in the elementary grades are initiated into approximations of the practices employed by STEM professionals to germinate, revise, and maintain knowledge. The design of learning ecologies includes making informed bets about STEM practices that can be robustly and fruitfully approximated in classrooms. These commitments are accompanied by conjectures about (a) how these practices interact to develop new knowledge, (b) the kinds of tasks and means of articulation that will support this hypothetical development, and (c) how to establish and maintain settings in which children can participate in both the production and critique of these emerging concepts and practices. All of these aspects of design are orchestrated by teachers, so teaching and learning are viewed as coupled, a perspective in the learning sciences that is most directly advanced by an approach known as design research. I illustrate this epistemic perspective on learning with two examples of design research conducted to introduce children to the signature practice of the sciences, modeling. The first example traces fifth- and sixth-grade students' (ages 10,11) induction into statistical practices of visualizing, measuring, and modeling variability. Engaging with these practices supported students' development of new ways of conceiving of samples as simultaneously a distribution of outcomes from a portion of a repeated stochastic process (a sample) and as distributed (a sampling distribution). These experiences initiated a new way of thinking about inference under conditions of uncertainty, an essential form of inference in sciences. The second example describes how young (ages 6,7) and older students (age 11) experienced the essential dialectic between performative and representational aspects of modeling as they noticed and explained similarities and differences among local ecosystems (prairie, forest, and pond). On the performative side, children worked to achieve a material grip on ecosystems by designing investigations, choosing appropriate tools, and developing measures to make the workings of these systems visible. On the representational side, children invented and revised inscriptions of material arrangements and established circulation (mutual reference) among these inscriptions to develop understanding of ecosystem functioning. I conclude with suggestions for productive new directions in research to support children's participation in the epistemology of modeling.

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BUILDING HYBRID MINDS: PEDAGOGY IN THE AGE OF LEARNING MACHINES

*Machines that learn and discover are now a critical part of science practice.
How can science education adapt to this change?*

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There is now consensus in the philosophy of science that building *explicit* models of natural phenomena is a core practice that supports scientific discovery. Following this, pedagogy based on the building of explicit models is central to the design of science learning.

However, discovery practices in contemporary science have changed — towards building *opaque* computational models, which do not provide explicit explanations. Such models dominate in the fast-developing *engineering sciences* (bioengineering, material science, systems/synthetic biology, robotics, artificial intelligence etc.), where the key objective is not developing explicit accounts, but *building*, *controlling* and *manipulating* novel synthetic artifacts, which mimic complex natural phenomena (neurons, metabolic networks, organism behavior, shape-memory etc.).

In most engineering science situations, where such synthetic artifacts are built in tandem with computational models, it is not possible to develop explicit accounts, even in principle. This is because such computational models are built as a last cognitive resort — when the non-linear interactions that are part of complex target systems are beyond both standard explicit modeling approaches and the human imagination. Opaque computational approaches (such as machine learning) are *required* to manage the overwhelming cognitive complexity in such situations.

This discovery practice has created a strange knowledge crisis, where machines built by humans discover patterns that humans cannot perceive. Machines also generate and 'meld' such patterns, to design novel solutions humans cannot imagine. Further, there is now a fast-developing 'hybrid intelligence' effort, based on interactive 'human-in-the-loop' video games, which allow two kinds of human-machine hybrids. One, such games allow crowds of novice players on the web to build novel scientific models of complex phenomena (such as protein folds, quantum computing, RNA, and neuronal networks), using their *tacit* sensory-motor capabilities, which are not available for conscious tracking and articulation. Second, in parallel, machine learning systems extract patterns from players' tacit moves, and generate novel models. Such hybrid systems create cognitive black boxes, where humans don't know what they are teaching the machine, and the machines don't know what they have learned. But they can together generate useful predictions and designs.

I will argue that the emergence of such hybrid modeling systems for discovery, and more broadly, *machines that learn and discover*, is a radical cognitive shift — similar to the emergence of tool use, language and literacy. These older cognitive shifts emerged across thousands of years, allowing learning and education systems to evolve in parallel. The ongoing shift to learning and discovery machines is occuring in internet time. To prepare students for this radical shift, science education needs to develop pedagogies that can evolve and adapt quickly, in step with fast developments in this domain.

Traditional pedagogical approaches (such as showing and telling) are not enough to adapt to this radical transition. The closest pedagogical process that appears suitable as a starting point is the *building* of prototypes, which is now promoted extensively through maker-spaces and tinkering labs. However, these building initiatives are not designed to support the building and manipulation of machine models for discovery. They are intended to kick start innovation cultures, where the building emphasis is on making of useful artifacts.

Learning to build and manipulate machines for discovery requires a new pedagogy of building. This is a very challenging and murky design problem. I will outline two directions the LSR group is pursuing to address this problem.

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CONCEPTS, METAPHORS AND CONCEPTUAL CHANGE IN SCIENCE LEARNING: A CONCEPTUAL METAPHOR PERSPECTIVE

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One of the main goals of the field of cognitive linguistics is to identify the many subtle conceptual construals implicit in linguistic choices. This has included identifying vast patterns of metaphorical construals in everyday language use not usually recognized as metaphorical. For example, time is conceptualized in terms of movement in space (as in *winter is coming; I can't wait until we get to summer*) and sometimes as a resource (as in *don't waste more time*; *time is running out*). Other examples (among many identified in the literature) are emotional states construed as containers (as in *I'm in a bad mood*; *he's in love*); goals are construed as destinations (as in *I'm moving in the right direction in my career*); and causes are construed as forces (as in *the performance lifted the crowd to their feet*). The theory of conceptual metaphor, developed based on these analyses, makes two central claims: that metaphorical expressions reflect underlying systematic mappings between conceptual domains; and that abstract conceptual domains are understood metaphorically in terms of more concrete, experiential knowledge. This more concrete knowledge is in the form of image schemas – that is, abstractions from repeated sensorimotor experiences - such as containment, moving objects, path, and forced movement. These claims offer those of us interested in science learning a way of thinking about how an understanding of abstract scientific concepts might be acquired. We have shown that even scientific concepts as abstract as the concept of energy are construed metaphorically in terms of image schemas: energy exchange can be construed as movement of a substance (as in *put energy into the gas*); forms of energy can be construed as containers (as in *the energy was stored in potential chemical energy*); and energy conservation book-keeping can be done construing energy in terms of a part-whole schema (as in *part of the system's energy was in the kinetic energy of the particles*). A lot of research on science learning and instruction over the last decade or so has used ideas from the theory of conceptual metaphor. This work has shown the relevance of a conceptual metaphor perspective to characterizing expert scientific understanding and reasoning, assessing and characterizing learner conceptions, describing the process of conceptual change, selecting and designing instructional representations and analogies and designing science curricula. In this talk, I will review this research, highlighting in particular how a conceptual metaphor perspective contributes to understanding conceptual change in science learning and what new questions it suggests. But I will argue that for substantial progress to be made in using a conceptual metaphor perspective to understand conceptual change, we need a clearer account of where conceptual metaphors fit in a theory of concepts. Specifically, I will argue that it is useful to integrate the perspective of conceptual metaphor with a view of concepts that emphasizes both how a concept refer to things in the world and participates in an inferential network.

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LEVELS OF ABSTRACTION IN SCHOOL ARITHMETIC

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In my article of A critique of the structure of U.S. elementary school mathematics (Ma, 2013), I discussed two organization types of elementary school mathematics. One has a "core-subject structure," and the other "a strands structure." I used the Chinese elementary school math standards before 2001 and the U. S. NCTM Standards as the examples to illustrate a comparison between them (Figure 1):

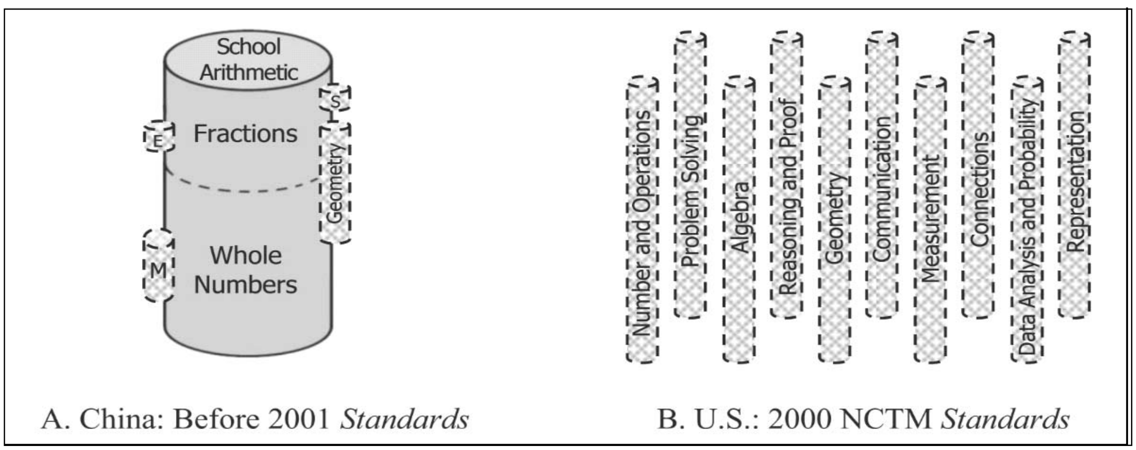

Figure 1. Two organizations of elementary school mathematics.

Example A has a "core-subject structure." The large gray cylinder in the center represents school arithmetic. Its solid outline indicates that it is a "self-contained subject." School arithmetic consists of two parts: whole numbers and fractions. Knowledge of whole numbers is the foundation upon which knowledge of fractions is built. The smaller cylinders represent the four other components of elementary mathematics, shown according to the order in which they appear in instruction. These are: measurement (M), elementary geometry, simple equations (E), and simple statistics (S). The core subject of elementary mathematics is what I call "school arithmetic." The subject of school arithmetic was constructed following the model of Euclid's *The Elements*. Although it took several decades to be comprehensively developed, its feature of being self-contained never changed. That feature ensures the consistency of elementary mathematics contents with school arithmetic as the core.

Example B has a "strands structure." Its components are juxtaposed, but not connected. Each of the ten cylinders represents one standard in *Principles and Standards for School Mathematics.* No self-contained subject is shown. This type of structure has existed in the U.S. for almost fifty years, since the beginning of the 1960s. The number and the components in a "Strands Structure" can be frequently changed and replaced, according to the different visions of the education policy makers. In this way, the consistency becomes a "luxury" hard to attain.

In the article The Theory of School Arithmetic: Whole Numbers (Ma & Kessel, 2018), Kessel and I pointed out that the idea of "unit one" is the fundamental concept on which the subject of school arithmetic is built on. We also addressed on several stages that the concept of "unit one" evolves in whole numbers, and how they may inspire students' abstractive thinking step by step.

In this speech I would like to expand the issue into fractions. A more detailed description of the evolution of the concept of "unit one" in school arithmetic, from concrete to abstract, from simple to sophisticated, will be discussed.

1) One-digit numbers. Addition and subtraction exclusively with one-digit numbers;
2) Multi-digit numbers. Addition and subtraction with whole numbers;
3) Multiplication and division with whole numbers;
4) The four fundamental operations of whole numbers;
5) Fractions. Addition and subtraction with fractions;
6) Multiplication with fractions;
7) Division with fractions;
8) The four fundamental operations of fractions.

The Fig. 2 presents the eight levels of abstraction levels of the concept of unit one in school arithmetic:

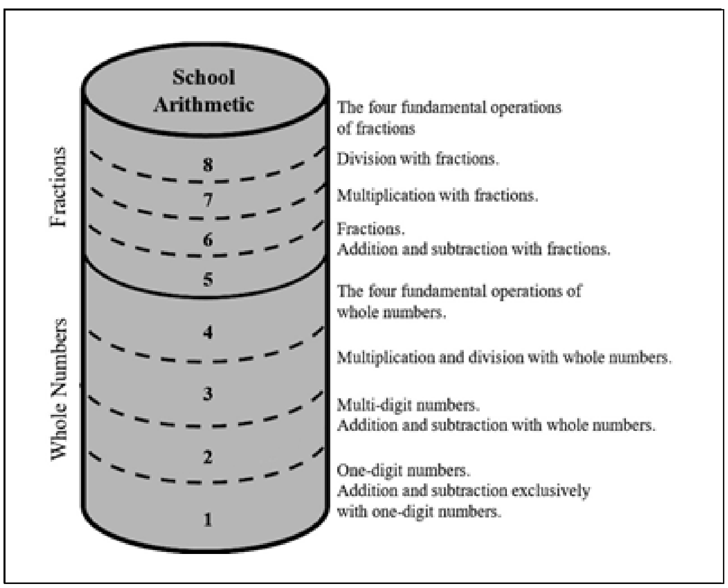

Figure 2. Eight abstraction levels of the concept of unit one in school arithmetic

I will use word problems to illustrate these eight levels of abstraction.

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Strand 1

Historical, Philosophical and Socio-cultural Studies of STME Implications for Education

NATURE OF SCIENCE: EMBEDDING SCHOOL SCIENCE IN ITS EPISTEMOLOGICAL PERSPECTIVES

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Nature of science as an educational goal and as an essential component of scientific literacy encompasses explicit development of an informed understanding of the interrelationship between the product and process aspects of science by embedding science teaching and learning in its epistemological bases. Several justifications underpin the spurt in advocacy for inclusion of the 'nature of science' as a cognitive educational outcome and representing the same in a science curriculum. This article presents a synoptic view of the meaning assigned to the term nature of science and henceforth it presents a review of the justifications offered for its inclusion in the science curriculum. Finally, the school science curriculum and the curriculum guidelines for science education at the school level are introspected with the nature of science as an educational goal.

INTRODUCTION

Scientific knowledge along with its practical ramifications in the form of technology has occupied an unprecedented place in the overall history of human civilization and has significantly contributed towards the development of a global culture. UNESCO justifiably emphasizes the development of scientific and technological literacy as is evident in its Project 2000+ Declaration. The significance of science and technological literacy is unanimously acknowledged with the wider social reverberations of the same in the present scenario (Jenkins, 1994). The phenomenal change eventually justifies the concern for achieving some level of understanding of science by the citizenry.

Scientific literacy (SL) has in the recent decades emerged as the primary goal of science education under the auspices of the contemporary reform movement advocating science education for every child (AAAS, 1993; Lee, 97) within a social and cultural context of the child and widespread acceptance of constructivist learning paradigm (AAAS, 93; Staver, 1998) with an overall aim to diffuse SL among all individuals.

SCIENTIFIC LITERACY AND NATURE OF SCIENCE

SL is a widely acknowledged educational goal and at the same time it is also considered as a contested term. Laugksch (2000) claimed that there are different interest groups related to the concept of scientific literacy that interpret the meaning of the term in accordance with their specific interests and purposes. Laugksch classifies the definitions of scientific literacy into three broad categories. The first category includes definitions that justify SL for the intellectual value associated with the term and highlights the significance of SL for its own intellectual sake rather than some instrumental purpose. SL is also defined in terms of the acquisition of certain context-free basic skills that help them understand science and its methods. Finally, SL is defined in terms of the application of the knowledge and skills in science in the social context and hence bringing in a humanistic perspective in the conceptualization of scientific literacy. The usefulness of being scientifically literate in a different social and cultural arena of life is the guiding perspective of those affiliated to this category. The third perspective on the meaning of SL is used as the general context for discussions about the Nature of Science (NOS).

The social and cultural perspective on defining SL is considered as instrumental in everyday decision-making situations of everyday social life particularly those related to science (National Research Council, 1996). NRC (1996) interprets SL as the minimum understanding required for "personal decision making, participation in civic and cultural affairs and economic productivity" (p.22). Such decision making capabilities are considered as the core of democratic citizenship. Adopting a similar perspective, OECD/PISA defined scientific literacy as "...the capacity to use scientific knowledge, to identify questions and to draw evidence based conclusions to understand and make decisions about the natural world and the changes made to it through human activity" (Gilbert, 2004, p.40). Thus SL is conceptually linked with education for a democratic citizenship.

The social and cultural perspective of SL is a multidimensional concept and it includes Nature of Science (NOS) as one of its essential components beside understanding the content in science and the processes of science. NOS refers to the set of values, assumptions and limitations regarding the scientific knowledge and scientific processes and hence is conceptually linked to the epistemology of science. Attainment of the goal of scientific literacy is then, an outcome of the concerted interaction of the three aspects of science education in the school science experiences. All three aspects are equally important in any curricula of science education that aims to foster scientific literacy among the students.

UNDERSTANDING NATURE OF SCIENCE

NOS is a common phrase used by the science educators‘ community as a description of the characteristics of science and hence is conceptually related to the philosophy of science in general and more specifically with the epistemology of science, even though the sociologists of science, historians of science and the scientists also have their interests in NOS (Mc Comas. 1998). A common issue transcending across all the interest groups is the conception of the epistemological underpinnings of science- the basic premises that justifies and validates scientific knowledge. With respect to the epistemological base of science, there exists at least two different positions viz. the ontological position of realism and that of anti-realism. The realists conceive nature as having an independent existence with respect to human perceptions and that such independent reality can be cognized in an absolute sense through the methods of science. The science curricula therefore ought to reflect this objective and empirical characteristic of science.

However it is the representation of science in school curriculum that has been questioned in light of the epistemological underpinnings of science. The traditional science curricula represent scientific knowledge as an exact description of things as they exists in reality that was made known by the disinterested and objective outlook of the scientists who provide conclusive verifications of their ideas through direct observation of nature aided by experimentation. Such science curriculum is grossly misrepresented. Von Glasersfeld (1995) claimed that the realists stand on the truthfulness of reality cannot be logically established as “the truth of any particular piece of knowledge” need comparison with that which is being known which again is logically not possible as it will involve yet ‘another act of knowing”(p.6).

The criticism raised against naïve realism caused the alternative epistemological perspective gained currency (Leach, et., al., 1996). The alternative perspective on NOS that emerged and gained importance is commonly termed as the constructivist perspective with an instrumentalist ontology (Matthews, 1998). Constructivist perspective is fundamentally an empiricist in its approach (Staver, 1998) as knowledge is not a simple matter of discovery and verification and rather it is a matter of construction wherein an individual engaged in cognition tries to make out a sense of his sensory impressions. Thus, there exists overlap between the different stands on the NOS. The constructivist perspective on NOS then advocates for a different stand on representation of NOS in science curriculum.

It is owing to the degree of sophistication involved in discussions centered on NOS and the complexity involved therein, that many consider NOS as inaccessible for the school level students and hence make it devoid of its educational sheen (Abd-El-Khallick et al, 1998). However, the contention regarding NOS are basically related to the issues related to ontological positions vis a vis science. However, there are common grounds as well that provide promising prospects for NOS as an educational outcomes. The consensus view that emerged on the NOS is considered as all - philosophers, historians of science, scientists and science educators (Mc Comas, 1998). For example, Matthews (1998) draws the common ground between realists and constructivists and highlights that both acknowledge the changing nature of scientific theories, based on empirical evidences and the research agenda of the scientists are socially and culturally influenced. The existence of common grounds unambiguously makes teaching and learning of Nature of Science feasible and practical.

NATURE OF SCIENCE: CONSENSUS VIEW

Researchers have tried to arrive at a consensus view on NOS that is the best compromise of the different positions held by the philosophers’ with respect to NOS and that is relevant for the young students (Bell et al, 2003). NOS is defined in a pedagogically relevant way as the “*values and underlying assumptions …intrinsic to scientific knowledge including the influences and limitations that result from science as a human endeavor* (Schwartz et al 2004, p611). This definition of NOS is pedagogically represented in form of a set of agreed upon ‘tenets’ (Efflin, et.al., 1999) and enable comprehending science as a body of knowledge as well as a process to arrive at the knowledge (NRC, 1996; Duschl et.al., 1990; Hodson, 1998; Aikenhead & Ryan, 1992). These tenets are listed as below: Science is an attempt to explain natural phenomena; Scientific knowledge is obtained through scientific inquiry that includes both observation and inference; Observations are basically theory laden i.e. what is observed and how it is to be observed is guided by the scientists’ theory/

hypotheses; Inferences drawn from the verifiable data is subjective in nature and there are possibilities of disagreement among scientists; Science yields knowledge that is verifiable being justified by observation, experimental evidence, rational arguments and skepticism; The nature of observation and inference in scientific process explains role of creativity in science; Laws and Theories, as the product of science, are related but different from each other and serve different roles in science; Scientific Knowledge while durable has a tentative character. Science has a social and cultural dimension; Science and technology are interrelated but not the same (McComas, 1998; NRC, 1996; Abd-El-Khallick, 1998).

NOS AND CURRICULAR SHIFT

Nature of science is a vital learning outcome that establishes the link between science content knowledge and the processes of science. Advocacy for NOS as an educational outcome has sound theoretical and practical bases. NOS is also construed as the epistemological beliefs (EB) in context of scientific knowledge, where epistemological beliefs relates to what one believes regarding the nature of knowledge and its development (Hofer and Pintrich, 1997) that has been established to be developed among young adolescents as well (Schommer,1993). Further, studies have established that sophistication of the epistemological beliefs is related to the way one processes information and the value one places on that knowledge (Hofer and Pintrich, 1997; Perry, 1970; Carey et al, 1989). NOS being science epistemological beliefs, influences one's way of processing scientific knowledge and applying it in different contexts (Songer & Linn, 1991; Staver, 1998). It also influences one's orientation towards learning of science (Songer and Linn, 1991; Lederman, 1992; Tsai, 1998), enhance students' interest in science (Mc.Comas, 1998) and assist them in reflecting on knowledge content (Larochelle and Desautels, 1991). The way in which students understand NOS influences their conceptual understanding of science content knowledge (Songer and Linn, 1991; Staver, 1998) and reflecting on knowledge content (Larochelle and Desautels, 1991).

Further, understanding of NOS is essential to understand the way scientific knowledge is created along with its limitations. Such an understanding is deemed essential for democratic participation of citizens in social issues particularly those related to science. The ever increasing nexus between social issues and their conceptual link with science and technology is an indication of the even greater significance that will be gained by the concept of NOS. Shamos (1995), while qualifying the importance of NOS, emphasized on defining scientific literacy overwhelmingly in terms of understanding of NOS rather than in terms of content knowledge (quoted by Laugksch, 2000). Millar and Osborn (1998), in their important document *Beyond 2000*, maintains that for a majority of students who are future citizens in different roles rather than future scientists, the core school science curriculum should be one that focuses on *knowledge about* science rather than *knowledge in* science where knowledge about science exclusively includes an understanding of NOS. Thus, *science for citizenship* aims at developing the citizens' capabilities to actively participate in debates and discussions related to such socio-scientific issues (AAS, 1989, Driver et al, 1996, Jenkins, 1999). However, the extent of participation and the quality of decision in such issues depend on the individuals' understanding of the scientific enterprise (Kang et al, 2004; Sadler, 2004) thereby substantiating the salience of NOS to citizenship education.

Summarily it can be claimed that NOS is pedagogically represented as set of cognitive learning outcomes that need to be provided proper representation in science curriculum at the school level. As the cultural context provides the necessary tools for the individuals in the meaning making process (Vygotsky, 1962), the norms and values of science as a culture need to be exhibited before the students (Driver, 1994, p.6).

Almost all the major curricular reforms in the second half of the twentieth century held the Armstrong's assumption that the students will understand the NOS through different science process skills, science content knowledge and scientific inquiry. The major curricular reforms such as Biological Science Curriculum Studies (BSCS), Nuffield Physics, and Physical Science Curriculum Studies (PSCS) laid a greater emphasis on the process aspect of science with the assumption that it will help students learn the true NOS.

However, the implicit approach to develop NOS among students came under severe criticism by the dawn of the twentieth century giving way to more vocal arguments in favor of teaching NOS in an explicit way. Millar and Driver (1987) highlighted the myth of dichotomous view on NOS as content and process and concluded that both the content and the processes of science are intertwined and interdependent for the learners. The study related to NOS and BSCS gave a severe blow to this basic assumption when it was concluded that even a science curriculum with emphasis on the process aspect of science like BSCS failed to develop informed understanding of NOS among the students (Meichtry, 1992) that further supported similar views presented earlier (Lederman, 1992; Abd-El-Khallick & Lederman, 2000).

Currently, diverse contexts are being explored to provide overt teaching and learning of NOS. Scientific Inquiry is still the most favorable and popular context, however in a different form with more emphasis on students active engagement stimulating their thought processes, explored by the researchers for developing informed understanding of NOS (Bianchini & Colburn,2000; Schwartz, et., al., 2001). Historical development of scientific knowledge is also researched for its efficacy in explicitly teaching the NOS principles and has been reported to be a suitable pedagogical approach (Abd-el-Khallick, 1998). Recently, socio-scientific issues are being explored as a pedagogical innovation for explicit discussion on assumptions of science (Sadler, et., al., 2004). Finally, modification in the science text books are also recommended to include overtly expressed section on NOS (McComas, 2003).

NATURE OF SCIENCE AND SCIENCE CURRICULUM: REFLECTIONS ON INDIAN CONTEXT

A brief but relevant understanding of NOS is acknowledged by the curriculum frameworks in Indian context (NCF, 2005) that in turn reflects the emphasis laid on including instructions pertaining to NOS earlier in the academic career (Kang, et. al., 2004). It is justifiably claimed that the link between the science content, science processes and NOS must be overtly made apparent by the teachers and that the "assessment of student`s prior knowledge" related to NOS must be used in the curriculum development (Meichtry, 1992, p. 405). NCERT (1998) in its National Curriculum Guidelines of Syllabus has identified NOS a long back as one of the seven dimensions of science curriculum that was again reiterated NCF (2005). It explicitly states that "Good Science Education is true to child, true to life and true to science" (NCF, 2005, p.46). Science curriculum can be true to science if it presents a true image of science in the classroom and true to ‘life` if the image thus created in the classroom enable the individual, to apply and use that knowledge in real life context including the socio-cultural context.

Unfortunately, the pedagogical approaches to NOS are missing from these documents that reflect their implicit approach towards this educational goal. A closer inspection of the curriculum documents reflect that the pedagogical approach lingers around the process or inquiry approach that unfortunately has yet to be translated into effective classroom practices. It will not be an exaggeration to claim that the curricular approach in vogue for science education is apt to exclude the attainment of vital components of scientific literacy.

The curricular documents grossly failed to explicate exactly what is to be understood by NOS and how to incorporate the same in classroom teaching and learning (Rai, 2009). The scenario raises skepticism with respect to achievement of the goals of NOS. The spurt in advocacy for curricular and instructional modifications with the aim to develop informed understanding of NOS among the students, observed across several nations, should find a place in the concerns of the curriculum policy framers and science educators along with exploration of the innovations (as mentioned in the previous section) in the Indian context. Empirical studies related to NOS could be broadly classified into five categories or encompassing five different themes viz. those related to students’ conceptions of the NOS; teachers’ conception of NOS; assessment of NOS and interventions; relationships between teachers’ conceptions of NOS, classroom practice, and students conception of NOS; and development and validation of instruments for assessment of NOS (Lederman, 1992). Studies are needed in each of these areas as well as a rich empirical database on students’ existing framework of knowledge regarding NOS (Kang, Scharmann, & Noh, 2004) is direly needed in the Indian context.

The ambiguity with respect to teaching and learning of NOS in the curriculum frameworks developed from time to time, paucity of empirical studies related to understanding of NOS by the school going students and the instructional strategies related to teaching and learning of the same, neglect of the different principles of NOS in the reputed science text books together manifests the need to rethink about the status of school science vis-à-vis international trend.

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ETHICS AND SCIENCE EDUCATION IN A WICKED WORLD

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Wicked socioecological issues pose challenging ethical dilemmas related to both human and nonhuman life on this planet. This paper makes the case that science education must enable students to understand environmental issues not just in terms of science content but also from appropriate ethical standpoints. Some ethical frameworks for understanding environmental issues have been proposed in the field of science and environmental education. However, these ethical frameworks were developed in an era in which technology seemed to power limitless economic growth, environmental sustainability was not considered mutually exclusive with such growth, and we had not yet entered the new age of unprecedented ecological catastrophes. In this paper, therefore, I also make the plea for a critical examination of the relevance of the current ethical frameworks for informing the role of science education in the new Anthropocene epoch.

INTRODUCTION

The latest report of the Intergovernmental Panel on Climate Change (IPCC, 2018) makes it abundantly clear that unless prompt, far-reaching, and unparalleled changes are undertaken to transform the relationship humans have with the rest of the world, our planet is headed for a catastrophic future much earlier than expected. I believe that science education has an important role to play in preparing future citizens to mitigate and cope with the disastrous effects of climate change and other environmental crises of the Anthropocene epoch; crises that our current generation of leadership have utterly failed to address. This paper makes the case that an important step in this direction would be to enable students to understand environmental issues not just in terms of science content but also and equally importantly from appropriate ethical standpoints. As I argue in this paper this is because environmental issues are quintessential *wicked problems*, which are "defined by high complexity, uncertainty, and contested social values" (Miller, 2003, p. 279). Thus, environmental issues pose challenging ethical dilemmas related to both human and nonhuman life on this planet with profound justice and equity implications of environmental problems for poor and marginalized people. Though we see promising efforts in the United Kingdom, New Zealand a few other countries, unfortunately, in the rest of the world there currently appears to be little movement towards inclusion of ethics as a component in the intended official science curricula (Reiss, 2008; Jones, et. al, 2007).

Of course, this is not to say that official science curricula are devoid of implicit or explicit ethical dimensions. But research (Bazzul, 2016; Sharma & Buxton, 2018) appears to indicate that the ethical standpoints tacitly implicated in the intended and enacted science curricula hinder rather than help students both in understanding and in taking ethically just actions towards ameliorating environmental problems. Some ethical frameworks have been proposed in the field of environmental ethics and environmental education for understanding environmental issues from an ethical standpoint (Palmer, 2013; Saunders and Rennie, 2013). Most of these ethical frameworks were developed in an era where technology powered limitless economic growth and environmental sustainability were not considered mutually exclusive (WCED, 1987). Therefore, in this paper I assert that it is important to (a) critically examine the relevance of these ethical frameworks in the current Anthropocene epoch, and (b) explore the meta-ethical foundations of alternative ethical frameworks that might be better suited for inclusion as components of science education for this new era of unprecedented wicked environmental problems. I believe that this examination is an important step toward the development of the philosophical foundations of ethical reasoning that needs to become a critical part of science education in the current era of ecological catastrophes.

THE WICKED ETHICAL DILEMMAS OF ENVIRONMENTAL ISSUES

Ethics is about answering the question: “What is the right thing to do”? Unfortunately, we live in an extremely complex and interconnected world where it is often not easy to decide what is the right thing to do, especially regarding socioecological issues. Let me illustrate this challenge with an example from the United States, where I currently live and work. Imagine that a student in the United States learns in her science classroom one day that bananas, the most consumed fruit in the United States, come from plantations that have caused massive destruction of rainforests in South and Central America (Clay, 2013). This student may decide that a boycott of bananas would be an ethical response to save rainforests from these plantations. In fact, many mainstream environmental groups, such as *Rainforest Relief,* do urge customers to “avoid purchasing bananas altogether and instead opt for fruit grown locally, such as apples, peaches, cherries or pears” (“Banana Industry’s Impact on Rainforests”, 2010). Alternately, some environmental groups, *Rainforest Trust* for example, may try to save rainforests by buying land in these regions so that they can be restored to their pristine ecological health (Butler, 2014). But as Vandermeer and Perfecto (2005) explain such actions alone may hurt the rainforests more than save them. The closure of banana plantations can result in loss of jobs for many plantation workers who often end up converting forests into subsistence farmlands in order to survive.

This student may instead decide that buying organic bananas might be the best option to help save the rain forests. However, the world currently is not in a position to feed all the people on the planet through organic farming (Seufert, Ramankutty & Foley, 2012). Organic bananas can be grown in only very specific conditions that severely limits the amount of land available for growing them. So even if there was a 10% percent drop in supply of regular bananas, the potential of growing organic bananas will not be able to meet the demand (Loza, 2016). The cost of production for organic bananas is much higher too. So, if only organically grown bananas were available in the grocery stores, it could mean that bananas would go back to being the exotic fruit for the rich like they were back in the 19th century. Again, higher prices may decrease demand, laying off plantation workers who return to unsustainable subsistence farming practices. Similar outcomes may result if our student adopts the strategy of raising money to buy up land for conservation and restoration. This is not likely to work either and may only lead to an ecological landscape marked by “isolated islands of tropical rain forest surrounded by a sea of pesticide-drenched modern agriculture, underpaid rural workers, and masses of landless peasants looking for some way to support their families" (Vandermeer & Perfecto, 2005, p. 13).

A seemingly simple question of whether to consume or boycott bananas ends up revealing a complex global assemblage of relations and entanglements involving local and distant human, non-human, material, social and cultural actors, and ethical-political dimensions. Simple actions such as a product boycott can indeed be counterproductive in resolving environmental issues because when we affect one strand of the complex web of causality inherent in these assemblages, the effects reverberate through the web in unanticipated ways to yield all kinds of desirable and undesirable outcomes. Thus, we find that an issue that on the surface looks very simple when unraveled reveals serious ethical quandaries that deserve to be acknowledged and tackled. This turns out to be the case for most environmental issues. Unsurprisingly, therefore, researchers have come to recognize environmental issues as a classic example of wicked problems (Brown, 2001; Camilus, 2008). Socioecological problems are wicked because they are "defined by high complexity, uncertainty, and contested social values" (Miller, 2013, p. 279). They arise from "the functioning and evolution of interconnected and complexly interacting socio-ecological systems" and defy solutions because "they are multicausal, intertwined with other problems, and value-laden" (Metzger & Curren, 2017, p. 94). As a result, environmental issues pose such difficult ethical dilemmas that unless one is equipped with appropriate ethical frameworks it becomes very hard to answer the question "what is the right thing to do?"

Unfortunately, wicked socioecological problems define our existence in the Anthropocene epoch, the geologic time period in which humans now substantially alter the Earth's geology and ecosystems. These challenges have long been known to affect the poor and marginalized sections of society disproportionately, and their impact on nonhuman life has been nothing short of disastrous (Walker, 2012). Any attempts to resolve such problems are also likely to create additional complex equity and socioecological justice implications for all kinds of life on this planet. As a result, as we saw in the examples above ethical dimensions are critical for both understanding and acting upon socioecological challenges (Brown, 2001).

ETHICAL LITERACY: WHAT DOES IT HAVE TO DO WITH SCIENCE EDUCATION?

Therefore, if we wish to remain hopeful about our future, we need to prepare our students as citizens who not only understand the 'wicked' nature of socioecological issues facing our planet but who are also deeply cognizant of the ethical implications of action as well as inaction on these challenges. Unfortunately, research (Sharma & Buxton, 2018) indicates that the implicit ethical stance in the school science curricula in the United States is problematic on several counts. Based on my past association with the Hoshangabad Science Teaching Program in Madhya Pradesh in the nineties and continued collaboration in science curriculum work with erstwhile colleagues in Eklavya in Bhopal and Hoshangabad, I am not sure if the situation is any better in India. In the United States for instance, school science curricula typically exhibit a strong belief in human exceptionalism. This view partitions the world into distinct social and natural domains, with human concerns at the center and issues related to nonhuman existence and survival at the periphery in deliberations on issues of resource allocation, survival and sustainability. This ethical stance is predicated on instrumental reasoning that, in concert with human exceptionalism, supports the commodification of the nonhuman aspects of our world. Research also shows that the ethical standpoint embedded in science curricula is neither explicitly articulated nor challenged in the science classrooms, thereby facilitating its uncritical reception by the students (Bazzul, 2016; Sharma & Buxton, 2018). In agreement with Poole et al. (2013) I find the absence of ethical learning to be “particularly problematic regarding environmental issues as management decisions must integrate ecological, social, and cultural dimensions, and a comprehension of the values underlying those decisions” (p. 349). It is hardly surprising, then, that when young adults in the United States are quizzed on the ethical implications of climate change, a clear majority is either unsure or does not see climate change as representing any moral or ethical issues (Markowitz, 2012).

It is therefore imperative that instruction on ethical implications becomes an explicit and critical component of science education not just in the United States and India, but in all nations of the world. Unfortunately, a number of powerful factors continue to frustrate inclusion of ethics in science education, including the naïve belief in value-free science, fears of indoctrination and relativism if ethics become part of school curricula, and the hegemony of neoliberal logic that insists on transmuting all non-economic and social values into economic values (Poole et al., 2013). However, in recent years, a strong case for inclusion of ethics in science curricula has been made by several science educators from different parts of the world (Reiss, 1999, 2011; Zeidler and Sadler, 2008). These calls for including ethics in science education have been made on the grounds of better understanding the nature of science, improvements in the ethical sensitivity, knowledge and judgement of students, and broadening participation of students who might otherwise show limited interest towards science learning. Science educators and researchers engaged in research and instruction on socio-scientific Issues in science education in particular have been a redoubtable votary of the inclusion of moral and ethical issues as critical components of scientific literacy (Sadler, 2004; Saunders and Rennie, 2013; Zeidler and Keefer, 2003).

CURRENT ETHICAL FRAMEWORKS IN SCIENCE EDUCATION

As things stand there is no dominant or preferred ethical framework in science and environmental education for instruction on environmental or socioscientific issues. Usually, proponents of inclusion of ethical literacy make the case for viewing scientific and environmental issues from a few dominant perspectives that constitute the scholarly canon on ethics in western societies (Reiss, 2003; Zeidler and Sadler, 2008; Beauchamp and Childress, 2001). Though these scholars articulate their frameworks differently, broadly speaking the different ethical frameworks articulated by them can be clubbed under *consequentialism*, *deontology* and *virtue ethics*.

Consequentialism: Ethical theories categorized under consequentialism make the case that only the consequences determine whether an action is ethically right or wrong. That is, if we wish to be ethical we should aim to bring about best outcomes. (Brennan and Lo, 2002).

Deontology: In contrast, deontological ethical theories maintain that it is in the context of our moral rules and duties that we decide what is the ethical thing to do. According to Palmer (2013), “Deontological theories in environmental ethics emphasize rules, principles, duties, rights or some combination of these. The basic idea is that we should adopt certain principles or respect certain rights, rather than that we are required always to maximize the good" (p. 199).

Virtue Ethics: In distinction with both consequentialism and deontology, virtue ethics conceptualizes ethical action in terms of virtues, like "kindness", "honesty", "sincerity" and "justice" (Brennan and Lo, 2002). In an environmental context, therefore, virtue ethics centers on "our attitudes and dispositions with respect to the environment" (Palmer, 2013 p. 200).

Unfortunately, indigenous and nonwestern ethical perspectives find themselves on the margins of scholarly conversations on ethical literacy in science and environmental education. Though, it is encouraging to note that a few scholars have argued for ethics of caring or feminist care ethics as important for inclusion in science education, or have advocated for pluralism in recognizing diverse ethical standpoints and values of different social groups (Lloro-Bidart, and Semenko, 2017; Reiss, 2003; Saunders and Rennie, 2013).

The ethical frameworks that dominate the conversation for inclusion of ethical literacy in science education are mostly the products of the age of enlightenment and modernity in the western world. They have been critiqued by environmental ethics scholars on theoretical grounds as well as for being out-of-step with the realities of life in the Anthropocene on several grounds. the main critiques of these modernist ethical frameworks can be summarized as follows:

1. They are based on a strong belief in human exceptionalism that leads students to partition the world in two distinct social and natural realms. This belief positions human concerns at the center and issues related to nonhuman existence and survival at the periphery (Sharma and Buxton, 2018).
2. Humans are reified as autonomous, rational, responsibilized individuals who can freely exercise their ethical agency independent of the socio-material context. Further, in any consideration of the situatedness of human ethical action, the environmental, nonhuman world is simply treated as a passive background (Whatmore, 1997).
3. Modernist ethical frameworks adhere to a material essentialism that characterizes the entities in the world with "a set of immutable properties that are relatively or absolutely autonomous from those of other entities and relatively enduring" (Castree, 2003, p. 4). Environmental ethicists are increasingly considering this material essentialism as untenable in the Anthropocene epoch that teems with "myriad part-human, part-organic, part-machinic entities that resist being represented within the conventional *taxon*", and owe their ontological properties to the varied discursive-material networks they are embedded in (Castree, 2003, p. 8).
4. These frameworks are anthropocentric in that they assume "capacity for reason as the definitive basis of a distinctively human ethical standing" (Whatmore, 1997, p. 38). This elevates the moral significance of humans vis-à-vis the nonhuman world, and serves to deprive the nonhuman world, such as birds, animals and trees, of an independent *ethical standing*, and visibility in any ethical calculus based on these frameworks (Valentine, 2004).

5. By consigning ethical consideration to instrumental logic (consequentialism), individual rights and responsibilities (deontology) and personal virtues (virtue ethics), these ethical frameworks work to depoliticize environmental ethical dilemmas. This depoliticization severely impoverishes the public sphere and diminishes the much-needed space for democratic contestation and decision-making on wicked environmental issues (Douglas, 2018).

In a way, therefore, these modernists ethical frameworks align well with the *Dominant Social Paradigm* of our times that has valorized low evaluation of the natural world for its own sake, compassion mainly for those near and dear, limitless economic growth and maximization of wealth, and instrumental, technocratic rationality (Harper and Snowden, 2017). It is hardly surprising, therefore, that the dominant pro-environment ideology continues to be *environmentalism*, which promotes the understanding that environmental dangers to the planet can be tackled within the existing political, economic and cultural order (Harrison and Boyd, 2018).

CONCLUSION

It is high time that we clearly recognize that we are in a new age of unprecedented ecological catastrophes. The scale of these crises has made it quite impossible to be confident about the planet's future without sounding naïve and out-of-touch. According to the newest report of the Intergovernmental Panel on Climate Change (IPCC, 2018) we only have a little more than a decade to undertake rapid and far-reaching transitions in our socioeconomic and industrial systems to limit the global mean temperature rise to 1.5^0C. That is, we have scarcely any time left to undertake actions designed to partially mitigate the impending threat to all life on earth. This is especially true for disadvantaged and vulnerable populations, including indigenous people and communities in poorer parts of the world, who are dependent upon agriculture or coastal livelihoods. As the already existing robust critique of modernist ethical frameworks indicates, it is quite likely that in the coming dystopian age in which "business as usual" approaches to science education as well as education in general might not work, we may need more radical ethical frameworks to guide our intended and enacted science curricula in schools all over the world (Sharma & Buxton, 2018; Whatmore, 1997). In addition to indigenous and feminist ethical perspectives, there are a range of ethical standpoints that have been proposed in response to the call for alternative frameworks that are immune from the aforementioned critiques of modernist frameworks. At one end we find frameworks like *non-centered democratic ecologism* that discards the nature-social dualism and encourages us to see the world as consisting of networks of nature-culture collectives (Latour, 2012). In these nature-culture collectives, non-humans are no longer relegated as objects with no ethical standing. Instead, they are included as constituent members of the social with the understanding that we extend equivalent (if not equal) ethical obligations to them as accorded to humans (Whatmore, 1997). At the other end, there exist standpoints like *post-environmentalism* that argues that we need not place any limits on economic activity to save our planet. We just need to unleash human creativity and ingenuity to find technological solutions for current environmental crises (Shellenberger and Nordhaus, 2011).

Unfortunately, however, there has been little discussion among science educators and researchers on the appropriate ethical frameworks for ethical literacy as part of K-12 science instruction. The only progress we have had so far is a recognition amongst a small group spread across different parts of the world that students need ethical literacy in order to better understand and be agential about socioscientific issues in science education. That is not enough. It is critically important that more members of the international science education community join this conversation by (a) recognizing the need to include ethical literacy as a part of science education; and (b) examining the philosophical foundations of current as well as alternative ethical frameworks to assess their adequacy for informing the role of science education in the new Anthropocene epoch. In the United States and a few other nations this conversation has already begun. It is my hope and plea that science educators in India too heed the call of the global socioecological moment we currently find ourselves in.

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"ASIBIZI": TEACHING HUMAN REPRODUCTION IN RURAL EASTERN CAPE SCHOOLS

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The primary focus of this paper is to explore the possible influence of cultural taboos when teaching human reproduction content knowledge by isiXhosa speaking teachers in rural secondary schools of the Eastern Cape, South Africa. Previous studies on Xhosa culture and the teaching of science have focused on the inclusion of indigenous knowledge in the curriculum, citing the need for cultural restoration and heritage. However, little research has focused on the experiences of rural teachers when teaching sexually related content to teenage learners of the same ethnic culture where traditional ways of behaviour are compelling within an ethnic grouping. In this paper, we used semi-structured qualitative questionnaires to explore the views of twenty-nine rural secondary school Life Sciences (Biology) teachers and one Life Sciences Education Specialist on the possibility of cultural taboos in terms of restricting language use when teaching human reproduction. Cultural taboo themes and examples of 'language conflict' were generated via thematic analysis of the data. The term 'language conflict' is taken from the isiXhosa word 'asibizi', which means, 'we do not talk about this'. The claim that is made is that cultural taboos embedded in cultural beliefs of Xhosa-speaking communities may be regarded as a fifth language issue that restricts the teaching of Life Sciences concepts of a sexual nature in terms of language and lexicon use; namely what teachers are allowed to say and the words that they are allowed to use.

Keywords: Teaching human reproduction, Xhosa cultural taboos, Fifth language, Rural secondary schools, South Africa.

INTRODUCTION

Research indicates that talking about sexually related content can be culturally offensive to certain groups worldwide (Buni, 2013; Kral & Schwab, 2012). This view is prevalent in Sub-Saharan African countries (Doidge & Lelliott, 2016; Mhakure & Otulaja, 2017). The question posed in this paper is whether the belief in cultural offensiveness is pervasive among indigenous Xhosa people living in traditional, rural villages of the Eastern Cape. Specifically, we explore Xhosa teachers' beliefs about how the cultural belief of '*asibizi*' - '*we do not talk about this*' – may impede the use of standard, academic language required for teaching human reproduction as prescribed in the Life Sciences curriculum (Dube & Lubben, 2011; Odora Hoppers, 2009).

Webb (2013) explored whether a culturally homogenous group such as the Xhosa people of the Eastern Cape share a common understanding of their indigenous knowledge (IK) and whether they see any value in including their cultural values in the science curriculum. The answers to both these questions were, in general, that they do have a common understanding (within limits) and that they do value the inclusion of indigenous understandings and worldviews when teaching science. However, there is a paucity of data on the existence and influence of traditional indigenous Xhosa cultural taboos in terms of teaching culturally sensitive topics such as human reproduction, particularly in rural Xhosa contexts, and the limitations they might impose in terms of the type of language and lexicon adopted by the teachers. As such, we explore the issue of how Xhosa culture may influence the teaching of human reproduction by Xhosa teachers. More so, we explore how homogeneity, that is, sharing common ethnicity with learners, influences the teachers' selection and delivery of human reproduction content such as menstruation, ejaculation, the structure of the testes and fertilisation.

Our concern with taboos is due to a general understanding that there are ingrained cultural beliefs that prevent talking about content viewed as culturally sensitive (Chilisa, 2012; Gee, 2008). Therefore, this paper explores cultural taboos and their possible influence on Xhosa teachers' use of language and lexicon (both in English and isiXhosa) when teaching human reproduction in rural schools situated in communities that hold firmly to their cultural practices and beliefs.

CULTURAL BELIEFS AND LANGUAGE

Central to the discussion is a previous study among Xhosa communities residing in rural Eastern Cape villages (Webb, 2013) which affirms the awareness of teachers, parents and pupils of the importance of integrating traditional knowledge in the school science curriculum. However, there is a paucity of data on the existence and influence of traditional Xhosa cultural taboos in terms of what teachers may say and what words they may use when teaching culturally sensitive topics such as human reproduction.

Culture is a 'social legacy the individual acquires from his group, a way of thinking, feeling, and believing' (Odora Hoppers, 2009, p. 604). Odora Hoppers (2002) advances a view that culture is the collective property of a group and manifests itself in learned behaviours, forming a pattern that shapes values from generation to generation. Foregrounding the issue of culture, Chilisa (2012) raises two types of values that are relevant for the study, namely: built-in, unconscious societal values which lead to preferences over certain things. Secondly, collectivism as a societal value that requires an individual to be part of a tightly knit social framework where people are loyal to the group. Further support for collectivism is proposed by Triandis (2018), who posits that culture is a 'collective phenomenon' (p. 4).

Pertinent to this paper, is the need to explore firstly whether the Xhosa teachers in rural areas are bound by collective, cultural taboos in the teaching of human reproduction. The second point is to determine whether conscious and unconscious societal values have influenced the participants to prefer using certain metaphorical words instead of standard biological terminology (Levinson, 2006; Nieto, 2006). Studies suggest that standard, biological terminology should be used for sexual terminology instead of euphemisms and colloquialisms (Chamany, Allen & Tanner., 2008; Doidge & Lelliot, 2016; Nieto, 2006).

Yore and Treagust (2006) note that there is a ‘three-language’ problem when teaching and learning science, namely the casual language used at home, the academic language of schooling, and then the peculiarities of the language of the discipline. An additional or ‘fourth language’ problem in South Africa is that the Language of Teaching and Learning in the majority of schools is English while the majority of learners are not English first language speakers (Webb, 2009). This issue is compounded in the Eastern Cape, where isiXhosa first-language speakers are most often taught in English by isiXhosa first-language teachers (Webb, 2009; 2013). In the rural contexts of the Eastern Cape, English can be considered to be a foreign language for most rural children (Webb, 2017), consequently bringing into even clearer focus the fourth language problem faced by learners and teachers. In the context of this paper, a fifth language problem could be taboo restrictions on language and lexicon, namely ‘*the things we do not talk about*’. As such, this study explores the issue of cultural taboos and the possible restrictions they may impose when teaching topics that are considered culturally sensitive.

METHODOLOGY

This small-scale exploratory research study, consisting of twenty-nine (29) secondary school Life Sciences (LS) teachers and one (1) LS Subject Education Specialist (SES), took place in the Ngcobo district of the Eastern Cape, South Africa. In the Department of Basic Education, an SES is responsible for managing all subject-specific teachers in an education district. The study comprised 12 male and 18 female respondents, with ages ranging from 25 to 60 years. In the new South African National Curriculum (Department of Basic Education, 2011), human reproduction content knowledge falls under Life Sciences (LS), a subject that used to be called Biology in the old curriculum. Therefore, the term LS has been used throughout the paper in keeping with current trends. Mindful of the aim of the study, data were generated on the participants’ current perceptions on teaching culturally sensitive sexual content (Taylor, 2011) framed in an ethos of mutual respect of their cultural heritage, human dignity and restoration of cultural identity (Webb, 2013).

As noted above, fieldwork with all respondents (n=30) was carried out in the Ngcobo District of the Eastern Cape. The setting is one of poorly maintained rural secondary schools (the schools in which the teachers who participated in this study teach) and poorly maintained, rugged and dusty gravel roads serving picturesque traditional villages of scattered rondavels and zinc-roofed rectangular houses from which learners in school uniform walk to school. Traditional herdsmen are often seen on horseback, while women dressed in Xhosa traditional attire are ubiquitous, carrying water buckets on their heads (no piped water is provided to residents in the area).

Qualitative exploratory, semi-structured questionnaires were issued to participants as the first step of a cyclic, flexible, design-based Participatory Action and Learning Action Recursive (PALAR) model (Zuber-Skerrit, 2009). Participants were issued with numbered questionnaires to be able to locate a specific questionnaire in case of errors. The aesthetic appearance of the questionnaire was colourful and simple, based on a study of Eastern Cape township teachers and learners of Xhosa ethnicity by Simayi and Lombard (2019) where it was found that doing so increased participants’ attention span. The first section of the questionnaire consisted of simple, closed questions with instructions where participants had to make a mark on the chosen demographical option. Closed questions were designed to ascertain demographic factors in order to accumulate empirical evidence about cultural issues and taboos and to provide contextual similarity, namely that of being a rural school with comparable ethnicity (Denzin, 2012). The second part of the questionnaire consisted of semi-structured questions, giving participants an opportunity to write how they felt when teaching human reproduction topics such as fertilisation, ejaculation, menstruation and sexual organs.

Inductive thematic data analysis was used to organise the data into patterns and themes, and a coding scheme was developed (Denzin, 2012). The first step of data analysis was used to describe statistics on the demographical area of the questionnaire (Creswell & Plano-Clark, 2007). The aim was to describe the target population, for example, Xhosa ethnicity, rural positioning of the school, LS as a subject taught and gender inclusivity to ensure that we had sampled appropriately. To give meaning and change raw data into meaningful patterns, we started with manual coding using sorting, writing and labelling (Creswell & Plano-Clark, 2007). Coding was used to group similar evidence and labelling to give a wider perspective. In the process, a story emerged as the text was used to generate themes and categories for understanding. The second step of thematic data analysis described the characteristics derived from the data coding in order to make connections between data and the original or emerging research question. The final step was the interpretation where participant responses were organised in the colour-coded categories to indicate emerging themes.

FINDINGS

Thematic analysis of the data generated by the questionnaire revealed that cultural taboos do restrict the teaching of human reproduction by the Xhosa ethnic group teachers who were part of this study. Specifically, findings indicate that there is a fifth language issue that is indicated by Xhosa cultural taboo restrictions on the language used to teach human reproduction. Examples of responses which speak to this claim are presented below. I represents a question while T represents a particular teacher’s response.

1 I: Do you think that teaching human reproduction content such as fertilisation, menstruation and ejaculation is part of the normal cultural conversation among young and old members of your culture? Explain your response.

2 T1: No, we don’t talk about sex issues in our homes. When I teach these topics ‘*I double up and make serious faces’* because these learners are naughty.

3 T2: *Asibizi*, meaning ‘we do not talk about those things’ and ‘*siyahlonipha’* meaning ‘we respect; we are disciplined’. We stay with these community members and are raised to respect our elderly people and cultural laws as forbearers and holders of authority in our culture.

4 T3: No, it’s called ‘*amanyala*’ meaning ‘vulgar and culturally offensive’. Traditionally we don’t talk about such things - ‘*asibizi’*.

The responses of T1, T2 and T3 illustrate the collective view that talking about sexual matters is taboo in the Xhosa culture. For example, T1’s view of ‘we don’t talk about sex in our homes’ reveals a fifth language issue (restriction) where Xhosa cultural taboos are inherent in an individual’s personal life and home environment. These taboos result in avoidance of talking about and pronouncing human reproduction terminology. Similar views, based on collective, prohibitive Xhosa beliefs on talking about sex-related issues, were shared by all the participants. For example, T2 uses the vernacular *asibizi* to illustrate the avoidance of naming human reproduction processes. A*sibizi* is also cited by T3, coupled with an explanation pointing out that tradition prohibits talking about human reproduction terms. Similarly, T3 believes that Xhosa cultural taboos regard talking about sexually related content as vulgar and culturally offensive (*amanyala* in isiXhosa); hence such talk is prohibited.

Compounding the teachers' situation is the matter of cultural identity in the form of *'asibizi'*, and *'siyahlonipha'* (we respect) as community members regard teachers as reservoirs of traditional and moral values where practices that have sustained Xhosa people for many generations have to be preserved. Teachers shared the view that they knew *inwardly* that they should 'avoid language of a sexual nature as it is offensive', confirming the role of culture as an ingrained, cultural belief that has unwritten rules. For example, T2 raises the issue of respect accorded to elderly community members as another cultural restrictive influence on teaching human reproduction. T2 points out that they have been raised to respect cultural laws and elders as holders of cultural authority.

Our findings show that Xhosa teachers share a common worldview where taboos induce feelings of shame, as indicated by T1. The issue of fear was glaring, where the respondent (T1) had to change facial expression. '*I double up*' is a colloquial expression used mainly by young people to explain *'changing the facial expression to a serious appearance'* as a defence mechanism when teaching the section on human reproduction. Furthermore, our findings indicate that Xhosa teachers share feelings of anxiety when teaching sexually related content to learners of similar Xhosa culture.

Anxiety was indicated by T4 where the respondent indicated that talking about sexual matters puts him in a *scary situation* because the problem is that the learners are waiting for the teacher to say those Xhosa terms that they know are prohibited in Xhosa culture. The challenge may be that learners will tell their parents in their traditional, rural environments and teachers may be viewed as disrespectful and far-removed from Xhosa practices.

Our findings reveal the need for cultural identification among Xhosa teachers. For example, T6 raises a compelling and collective authority that avoids talk about human reproduction, expressed as *'we must continue to be torchbearers of our culture and avoid using sex talk'*. Other respondents (T4, T5, T6) confirmed that Xhosa cultural taboos prevent them from talking about sexually related issues as something which is *not* done (T4) in our Xhosa homes when children grow up.

Also, our findings indicate that Xhosa cultural taboos are 'built-in' values and language that conflicts with what they are supposed to teach at school are, therefore, a fifth language issue. For instance, T5 believes that the school puts teachers in a difficult situation where they have to talk about these *things*. Difficulty and uneasiness in talking about human reproduction concepts can be seen from the teacher's avoidance of using standard biological concepts and terms, referring to them as *things.*

5 T4: Conversation about puberty and sexual parts is *not* something done in our Xhosa homes when children grow up. The problem is - learners know there are Xhosa words that are not talked about

in our culture. This puts me in a scary situation as I can't explain these things in my home language.
6 T5: It's our belief and we've been brought up to avoid talking about sexual issues - now at school, we are in a difficult situation as we have to talk about these things.
7 T6: We must continue to be torchbearers of our culture and avoid using sex talk while we have to teach the subject; that is a big language and moral problem to me at my age.

Our findings suggest a situation where Xhosa teachers are strongly influenced by collective, cultural taboos in the teaching of human reproduction in their rural spaces. We base this view on the excerpt, among others, from T2 '*we stay with these community members and are raised to respect our elderly people and cultural laws as forebearers and holders of authority in our culture'*. Further, T6 believes that '*we must continue to be torchbearers of our culture*', indicating an affinity to collectivism.

Living with elderly community members in a rural place and teaching their children, raises an internal conflict where the teacher believes he or she has to gain and maintain the respect of the elders by avoiding culturally offensive human reproduction language. Culturally offensive language is seen in T3's response '*No, it's called amanyala - vulgar',* raising a point that the teacher does not want to be seen as disrespectful, ill-disciplined or bad by village members. Therefore, it can be claimed that there is a fifth language cultural conflict with the demands of the curriculum that restricts the teaching of human reproduction in rural Eastern Cape schools where the teachers and pupils are homogeneously ethnically Xhosa.

As indicated earlier, this study is preliminary and explores the presence and influence of Xhosa cultural taboos when teaching human reproduction. Our findings raise a question pertaining to the delivery of quality teaching and learning, namely, how do Xhosa teachers teach a subject where they cannot say the standard, human reproductive terms? In line with this question, this research remains an ongoing process which aims at generating further findings and possible solutions during the next data collection phase of the study.

CONCLUSION

In this paper our principal claim, based on the empirical questionnaire data, is that cultural taboos embedded in cultural beliefs of Xhosa-speaking communities restrict the teaching of Life Sciences concepts of a sexual nature in terms of language and lexicon use; namely, what teachers are allowed to say and the words that they are allowed to use. Cultural taboos add an extra dimension to the challenges of the home, school and disciplinary language problems of science teaching as described by Yore and Treagust (2006). Such taboos go beyond the language challenges of learning in a second language as they do not depend on whether the teachers use English or the home language of their pupils. In other words, although the effects of taboos are reflected in language and lexicon, they appear to be independent of any particular language used as they are primarily embedded in the culture. Nevertheless, they still remain a language issue and can be seen as a 'fifth language issue' which needs to be considered when teaching science in schools situated in communities where such taboos exist.

While these findings are preliminary, the authenticity and homogeneity of the responses produced by the small sample of teachers in this study suggest that further research in this field should provide meaningful insights into issues hindering the teaching and learning of taboo topics. These insights could possibly be used to stimulate the development of teaching and learning strategies that, while respecting cultural beliefs, allow the required content and understandings expected by the curriculum to be delivered.

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SCIENCE AND SCIENTIFIC TEMPER

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According to the Constitution of India (Article 51 A), it is our fundamental duty to inculcate 'scientific temper'. National Curriculum Framework 2005 also looks at the development of scientific temper, as one of the aims of science education. Though scientific temper is not confined to science alone, the possibility of developing scientific temper seems higher in science, as it stands as the most reliable source of knowledge and understanding. We expect science teachers to help children to understand what is science and its influence on human life. So, it becomes important to understand what science teachers think of science. A teacher's identity gets constructed based on her belief, perceptions, experience, values, and judgments. Because a teacher has a moral influence on the students, these need to be examined (Bukor, 2011).

Keywords: *Scientific Temper, Nature of science, Method of science.*

SCIENCE TEACHERS' PERSPECTIVE ON SCIENCE AND SCIENTIFIC TEMPER

Science is a process of understanding the natural world, through the inquiry, in which one applies the methods of science such as – Observation, Induction, and deduction etc. Through inquiry, science explains the phenomenon/entity and provides justification for that for example by suggesting theories. Sarukkai writes scientific theories are unique because they not only describe but also explain and also do the job of unifying the diverse phenomenon (Sarukkai, 2012) "Explaining, categorizing, detecting causes, measuring and predicting are other aims of scientific activity" (Bird, 1998).

Science as knowledge is falsifiable (and verifiable to some extent) and changeable as the process— there is no fixed set of features, which makes something 'science'. According to Popper, a theory is scientific if it is falsifiable (Popper, 1992).

By considering the nature and methods of science, science education has been assigned for an important role of developing scientific temper — according to the national focus paper on teaching of science, one of the aims of science teaching is to develop scientific temper (ST) in students. "*Aim of science education is to cultivate 'scientific temper'- objectivity, critical thinking and freedom from fear and prejudice*." (National Focus Paper on Teaching of Science, 2006).

Scientific temper is an attitude, where one applies the methods of science in the day to day life, to solve the problems of individual and of society by taking the ethical/moral, social and epistemic values into consideration (Sharma, 2018). To have a scientific temper, one does not necessarily need to go through science education. But science education can help to inculcate scientific temper as the process of science education helps in internalizing the methods and value of science.

In India firstly Pandit Jawahar Lal Nehru introduced the term ‘Scientific Temper’ in 1946 in his book ‘Discovery of India’. He referred to scientific temper as “*a way of life, process of thinking, a method of acting and associating with fellow men*”. Nehru also believed that if India wants to develop strong and vibrant societies like European societies then it had to learn and behave scientifically. He mentioned scientific temper as one of the national goals. By scientific temper, Nehru meant “*fostering the empirical and rational way of thought and life*” (Parekh, 1991). According to article 51(A) of the Indian constitution, it is the fundamental duty of the citizens of India to develop scientific temper and having the spirit of inquiry.

The first statement on scientific temper (1981), given in a conference by Dr Raja Ramanna, Dr. PM Bhargava, and PN Haskar, also explains that it is important to have scientific temper for the survival and future of the nation. According to this statement, scientific temper (ST) should be fostered with care at the individual, institutional, social and political level (Pre-Proceeding from International Conference on Science Communication for Scientific Temper, 2012). In this conference, the need for developing scientific temper was identified and some areas were selected to develop scientific temper, education was one of them. According to the statement, scientific temper is neither an accumulation of knowledge nor rationalism, but rather it is an attitude of mind or the way we approach our problems.

METHOD

The purpose of the study was to understand science teachers, as well as teacher educators’ understanding of science and scientific temper. Regarding science, the focus was on nature, methods, and values of science. In education, teachers play an important role — we expect science teachers to help students to understand what is science and its influence on human life. So, it becomes important to understand what science teachers think of science. A teacher’s identity gets constructed based on her belief, perceptions, experience, values, and judgments. Because a teacher has a moral influence on the students, these need to be examined (Bukor, 2011). So, this study was an attempt to get an insight of science teachers and teacher educators’ understanding of science and scientific temper.

This qualitative study, which spanned for six weeks, was conducted at the Homi Bhabha Centre for Science Education (HBCSE), Tata Institute of Fundamental Research (TIFR), Mumbai. The study was done with eight school science teachers and two teacher educators, from an institute in Mumbai. All the science teachers are actively engaged in science teaching. Out of eight teachers, seven teachers hold a degree of master in science, and one teacher holds a degree of bachelor in science.

In the initial part of the study, teachers were asked to fill a questionnaire. The questionnaire responses were followed by semi-structured interviews. The questionnaire engages with nature and aims of science and attempts to understand science teachers' standpoint on various current socio-scientific issues. The interviews were more focused on the nature of science, methods, values of science and scientific temper.

The interview questions are given below. Other than these questions, the question 'when do you call something scientific?' or something similar to this was being asked, as almost all the participants (except one teacher) used the word 'scientific' in either interview or questionnaire.

Some of the interview questions were -
1 How is science important?
2. Does science help you to make life better? How?

According to you what are the objectives of science teaching?

Do you think science (as taught in the schools) has the potential to develop values in students? What values? What made you think so?

Do you think science is different from any other domain? How?
According to the constitution, it is our fundamental duty to have a scientific temper. What is scientific temper according to you?

Why there is a need to develop scientific temper? Do scientific temper plays any role in the development of society? How?

PARTICIPANTS' RESPONSES

The responses of the participants were quite different in some aspects and common in others – there were different kinds of understanding. On one end, a teacher, who has a good understanding of nature, methods, scientific temper and believed that science is influencing humans positively. On the other end, participants who had confusion about the impact of science on human lives and looked at science as a school subject, which has some information about the world.

Science teachers' perspectives on different themes

Nature of science: Most of the teachers think that science gives us 'facts' or description that of truth about the natural world. Only a few of the participants (two teachers and teacher educators) understood the falsifiability of science. Also, on a question "when do you call something scientific"(almost all the participants used this word, either in the questionnaire or in the discussion, except one participant). Five out of seven teachers answered "*something is scientific if, it can be proven*", the other two participants answered, "*If something follows a particular sequence and goes step by step*". It wasn't clear here if they were pointing at any regularity here. Most of the teachers look at description and justification as the crucial thing about science.

So, according to most of the science teachers, the nature of science is descriptive, where it tells us facts about the natural world and provides justification for these facts. Only two science teachers in the study mentioned that science also does the job of explaining the phenomenon.

Methods of science: Most of the participants considered observation and/or experiments as the methods employed in science. Only a few of them (two teachers) could identify induction, prediction, and heuristics as some other methods of science. Also, most of the participant thought that there is one particular sequence we follow in science, which is the scientific methodology. Some of the science teachers in the study thought that by doing activities we get to learn the scientific methods because students internalize the process.

Also, participants' understanding of the nature and method of science and scientific temper seems to be correlated. Participants who have shown scientific attitude towards some of the issues included in the questionnaire had a comparatively clearer understanding of the nature and methods involved in Science — they could identify prediction, heuristics, detailed and careful observations (rather than mere observations).

For example a teacher who understood about falsifiability of science. During the discussion on Sabarimala issue participant mentioned – "*we should allow around hundreds of women to go into the temple then only we can conclude something.*" The participant thinks, by experimenting we will get to know about cause and effect.

While another teacher, who believed that science tells us the truth only. On Sabarimala issue the participant mentioned – "*women should be focusing on work, there is no need to go to the temple.*"

Scientific Temper: According to the participants, scientific temper is an attitude/behaviour/ perspective/ ability, which can be developed through science education but science education is not necessary to have scientific temper. Some of the science teachers in the study believed that doing science and history of science helps in inculcating scientific temper. However, they could not explain how doing science helps in inculcating scientific temper.

While explaining scientific temper, most of the participants correlated it (scientific temper) with methods of science. They mentioned:

"*True observation and then analyzing— and rationalizing it over there with that attitude, this attitude is nothing but scientific temper*". (Teacher -1)

According to the participant we do careful observations when we have the scientific temper. (Teacher-2)
"*Lab work helps in developing scientific temper because we do experiments there*". (Teacher-4)

Values of Science: Almost all the participants believe that science education has the potential to develop some values (epistemic or ethical or social). The participants identified some of the epistemic, social and ethical values of science. In epistemic values, participants mainly looked at truthfulness, curiosity and scientific temper as some of the values. Also, most of the participants thought that Science makes us more sensitive towards the environment and social issues.

One participant had the belief that science is harming the existing value system. The participant mentioned – "*Now a days if you say something to the children, they ask many questions and do not listen and respect elders. Science and technology is harming our culture and values*"

Objectives of science teaching: Science teachers in the study mainly looked at constructing content knowledge as the aim of science teaching. Out of eight, five science teachers in the study mentioned that they taught Science to provide knowledge/ understanding of content to the students. Other two teachers mentioned that they teach science to develop scientific/ analytical thinking among students. While one teacher mentioned that by teaching Science, the teacher tries to develop certain skills in children— such as, the skills of doing activities (doing science).

Science and individuals' belief: Participants seemed to be in dilemma with regard to their belief because of their education in science and belief they held. They tried to prove their belief as scientific; for example a participant mentioned - Science should not influence our life, because it is uprooting us from the culture but on the other hand, the teacher tried to prove religious beliefs and rituals as scientific.

Probably, it was because of the education they have gone through. Probably their science education contributed to the perspective that one needs to have justification to believe in something.

By keeping the practices of science in mind participants tended to prove their cultural and religious belief as scientific. To prove those beliefs as scientific, teachers try to co-relate it with the concepts of Science or scientific knowledge. It seems like dressing up religion as science, as some of the philosophers also regard creationism as 'religion dressed up as science' (Bird, 1998).

For e.g. - To prove astrology as scientific, a participant mentioned - "*may be like gravitational force, the magnitude of the star's effect is very very less that we can't notice that, but definitely stars have an effect on us, same as our neighbours have an effect on us*".

One another participant mentioned; "*Scientific reason behind doing puja of the Peepal tree is that when we do puja we are spending more time under the tree, in that way women will get more oxygen, it is important because earlier women were cooking food on chulhas so, they were in contact of carbon dioxide for a long time*".

According to four participants, whatever our rituals and traditions are, all have a scientific reason behind. It is probably that we are not aware of all those reasons. Another three participants thought that there are some wrong practices in our religion, ritual, and culture, which are ethically not good and they are not logically consistent; these had to be abolished, but not all. So, in a way, there was a range in participants' opinions.

Some of the participants were being little diplomatic— politically correct in answering. For example, most of the teachers mentioned in the questionnaire that menstruation is a biological process, there is nothing impure in this. However, in interview some of them mentioned- "*why women want to go to temple during periods, they should better take rest*" or "*women should be focusing on work, there is no need to go to the temple.*"

CONCLUSION

Participants believed that science has the potential to develop some values, such as - scientific temper, which is an attitude/behaviour /ability/realization. But it's failing because we are more oriented towards content knowledge. So, they thought there is a requirement of something more apart from content knowledge.

Also, it was evident that science teachers in the study hold some alternate ideas and misconceptions about science and scientific temper and have not rationalized the aim of science education. This presents a need for emphasizing more on the nature and methods of science — the underlying philosophy of the subject in school science education and teacher professional development programmes along with the content knowledge. Additionally, the aims of science education needs to be explained/rationalized to science teachers.

The science teachers in the study tried to prove their belief as scientific — they tried to make some connections of their belief with the scientific knowledge they hold, even when science education is focused mostly on content knowledge. This indicates that there is some hope that by making adequate efforts (by focusing on the nature and methods of science along with content knowledge) our aim of developing scientific temper can be achieved through science education.

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ANALYSING WATER-RELATED TOPICS IN SCIENCE TEXTBOOKS FROM SUSTAINABILITY AND SOCIAL JUSTICE PERSPECTIVES

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This article explores how the Indian school science curriculum deals with social justice and sustainability with reference to water-related topics. The three pillars of sustainable development as put forth in Rio Earth Summit (1992) were used as the framework to explore sustainability and social justice perspectives in NCERT EVS (grade 3-5) and science (grade 6-10) textbooks. As the terms 'social justice', 'sustainability' and 'sustainable' are not mentioned frequently in the curriculum so the water-related topics were examined carefully to investigate signs of content related to sustainability and social justice using the key developed by Jóhannesson et al (2011). The analysis revealed that sustainability and social justice perspectives are discussed more in textbooks for primary and secondary level as compared to the upper primary level.

INTRODUCTION AND REVIEW OF LITERATURE

'Water is for one and all', this phrase implies equal access to water to everyone irrespective of one's class, caste, race or gender and, also for sustainable use of water to ensure the availability of potable water for future generations. The challenge to make potable water accessible to all is more pressing than ever due to lack of formal water provision, unequal distribution and water pollution.

The unjust exploitation of natural resources for economic development has given rise to many concerns. The relationship between development and environment led to the conceptualization of sustainable development (Adekunle, 2017). According to Langhelle (2000), the term 'sustainable' was first used in a report made by the working group within the World Council of Churches in 1976. He cited the following excerpt of the report from Birch et al. (1979)

> *The twin issues around which the world's future revolves are justice and ecology. 'Justice' points to the necessity of correcting maldistribution of the products of the Earth and of bridging the gap between rich and poor countries. 'Ecology' points to humanity's dependence upon the Earth. Society must be so organised as to sustain the Earth so that a sufficient quality of material and cultural life for humanity may itself be sustained indefinitely. A sustainable society which is unjust can hardly be worth sustaining. A just society that is unsustainable is self- defeating. Humanity now has the responsibility to make a deliberate transition to a just and sustainable global society*. (p.296)

This conceptualization of sustainable society clearly has a social justice mandate which got lost or subsumed within the discourse that conflated ‘development’ and ‘economic growth’. In Brundtland report (1987), sustainable development is defined as the development that meets the needs of the present without compromising the ability of the future generation to meet their own needs (Langhelle, 2000). Such conceptualization of sustainable development does not consider the existing social inequalities. The most widely conceived notion of sustainable development is highly anthropocentric though alternative ecocentric views are also put forth.

Agyeman, Bullard and Evans, (2002) argued that the concept of sustainability is not limited to environmental aspects only, it must consider the aspects of social justice where *questions of social needs and welfare, and economic opportunities are integrally related to environmental limits imposed by supporting ecosystems*. What role does class, race, caste, justice and equity play in sustainability? According to Agyeman (2008), inequity and injustice resulting from racism and classism [and casteism] is bad for the environment as well as for sustainability as broadly conceived. Langhelle (2000) also viewed social justice as an integral part of sustainable development. He opined that development and environmental policies, as well as the strategies and priorities, are greatly influenced by the way the relationship between social justice and sustainability is perceived.

In Rio Earth Summit, 1992, three pillars of sustainable development were put forth, which are: Environmental Protection (Environmental sustainability); Social welfare and cultural integrity (Social sustainability); and Economic development/prosperity (Economic sustainability) (Nightingale, 2019). The main objective of development is to maintain the balance between these three pillars to attain sustainability. According to Nightingale (2019), environmental sustainability is assumed to be the most important and the views vary from highly anthropocentric to ecocentric. Social sustainability mainly focuses on social justice dimension. Social justice supports the idea that everyone deserves equality in economic, political, and social rights, as well as equal access to important human rights (Adams & Bell, 2016). It aims for the total transformation of society to bring social justice by addressing social inequalities. Economic sustainability is argued to be the main pathway to sustainability (Rio Earth Summit, 1992). Many argue that economic growth is necessary for achieving sustainability. According to these people, poverty causes overexploitation of resources and therefore leads to environmental degradation. Whereas another group of people consider global capitalism as fundamentally unsustainable causing inequalities among societies and *overexploitation of ecosystems*. They advocate for alternative economic relations (Nightingale, 2019). Economic sustainability is given the most consideration while making policies on sustainable development.

Education for Sustainable development (ESD)

The central focus of ESD is to prepare students to become responsible citizens by enabling them to participate meaningfully in community-related issues and adopt a sustainable lifestyle by taking the responsibility for both themselves and future generations (de Haan, 2006). According to Wheeler (2000), ESD should aim at developing a deep understanding of complex environmental, economic and social systems and recognition of the importance of interconnectedness between these systems. According to McKeown and Hopkins (2007), most of the ESD models advocate an issue-based and interdisciplinary approach to bring together different perspectives towards a socially relevant contemporary issue. Science and technology plays an important role in the social and economic development of any society and many issues/concerns regarding sustainability have their links with science and technology either in their genesis or in solutions. Therefore, science education is at the core of the ESD.

Water-related issues like water pollution, the disappearance of water from lakes and rivers, depletion of groundwater etc. are in news since last two-three decades and now the situation has become severe. Now, many areas including major cities around the world, are facing water shortage and water contamination issues. There is a need to take immediate actions to sensitize people, students and common people alike towards such serious water crisis. The present paper aims to explore what water-related topics are covered and how sustainability and social justice perspectives are incorporated in NCERT EVS and science textbooks.

SAMPLE AND METHOD

For this study, NCERT EVS (Environmental Studies) textbooks for grade 3-5 and science textbooks for grade 6-10 were analysed from sustainability and social justice perspectives using the three pillars of sustainable development as put forth in Rio Earth Summit (1992) as the framework. NCERT textbooks are the most widely used textbooks in India. As recommended by NCF-2005, NCERT textbooks for primary level (EVS, grade 3-5) are based on an integrated approach, therefore science and social science are integrated as Environmental Studies. Although NCF-2005 advocates for integrated curricula, the syllabus represents collection curricula where themes are not connected but are isolated. Water-related topics are part of the syllabus at all grades, however, the topics are fragmented.

The descriptive content analysis method was used for textbook analysis. First, the chapters which included water-related topics were selected. Then, these chapters were analysed using the key developed by Johannesson et al. (2010) to study the signs of sustainable development. This key has seven characteristics: values, opinions and emotions about nature and environment; knowledge contributing to the sensible use of nature; welfare and public health; democracy, participation, and action competence; equality and multicultural issues; global awareness; and finally, economic development and future prospect. The selected chapters were read carefully and the content manifesting any of these characteristics was selected. The selected content was then categorised into social, environmental and economical aspects of sustainable development and analysed from the social justice perspective.

ANALYSIS AND DISCUSSION

The textbook analysis discussed in the following section will reveal what water-related topics are covered and, where and how sustainability and social justice perspectives are incorporated in NCERT EVS and science textbooks.

Water-related topics covered in the NCERT EVS (grade 3-5) and Science (6-10) textbooks
Water-related topics are covered in at all levels, primary (grade 3-5), upper primary (grade 6-8) and secondary

level (grade 9-10). There is at least one chapter or one section at each grade level which is devoted to 'water'; however, the content covered in these chapters is repetitive, focusing mainly on water sources, their use, water shortage, water pollution and rainwater harvesting. For example, surface water pollution is discussed through an example of river Ganga in grade 8 (Ch-18) and, also in grade 10 (Ch-16). Table 1.1 represents the water-related topics covered in science textbooks (grade 3-10).

Water related topics	**NCERT textbook (numbers indicate the grade level)**
Fundamental concepts: forms of water, properties, water cycle	3,5,6,7,9
Water availability	7
Sources: Fresh and salt water sources	3,6,7
Uses: domestic; Agricultural and Industrial	3,4,6,9
Water shortage	3,4,6,7
Initiatives to deal with water shortage: rain water harvesting, revival of lakes and ponds, sustainable use of water	3,5,6,10
Water pollution	4,7,8,9,10
Cultural references	3,5

Table 1: Water-related topics covered in the textbooks

The major emphasis in lower grades is on water shortage issues whereas in higher grades emphasis is shifted to water pollution. While discussing the uses of water, domestic and agricultural uses of water are discussed repeatedly in textbooks across the grades whereas industrial use of water is not discussed significantly. Also, in the case of water pollution, as contributing factors, domestic waste is discussed the most, followed by agricultural waste whereas, pollution caused by industrial waste is not discussed much in the textbooks. Moreover, throughout the grades, a major focus is on surface water and pollution of groundwater is discussed briefly only in the science textbook of grade 7. The extent and the severity of the impact of surface water and groundwater pollution on human and environment are not discussed appropriately.

The concept of sustainable development is explicitly introduced in science textbook for grade 10 in chapter-16 (Management of Natural Resources). Definition of sustainable development from the Brundtland Report (1987) is given.

> *The concept of sustainable development encourages forms of growth that meet current basic human needs while preserving the resources for the needs of future generations. (NCERT, 2006, grade-10, p268)*

Though no concrete example is provided in the textbooks to help students to understand the meaning of sustainable development, students have been encouraged to adopt environment-friendly habits and make changes in their lifestyle. Attempts have been made to sensitize students towards sensible use of water through activities like calculating how much water is needed per person per day, how much water is available for our use and by mentioning difficulties faced by people in water-scarce areas.

Sustainability perspective was found to be significantly incorporated in textbooks, however, social justice aspect was marginalized except few instances (discussed in the next section). Unlike sustainable development, the importance of social justice is not discussed explicitly anywhere in the textbooks. The interconnectedness of sustainable development and social justice is not brought forth in the textbooks.

In the upcoming sections, the water-related content covered in the textbooks is analysed from a social, environmental and economic perspective. Social justice perspective is discussed within each foresaid section.

SOCIAL AND CULTURAL ASPECTS RELATED TO WATER

Analysis revealed that the textbooks have mainly incorporated the perspective of rural and poor sub-urban societies of India Of the three levels, primary level textbooks were found to be incorporating social and cultural aspects of water-related topics significantly, like discussions on different practices like reuse of water, using 'tanka method' for rainwater harvesting etc. EVS textbook for grade 5 included discussion on how people in the past used to tackle the issue of water shortage sustainably by constructing stepwells and interconnected lake system to store rainwater for yearlong use and how the change in lifestyle of people and neglect of such sustainable water management systems led to water shortage issues at these places.

The EVS textbooks also included discussion on the water-related customs and cultural practices to depict the significance of water to people's lives, for instance, in EVS grade 5 textbook, there is a section on 'customs related to water' with pictures of a bride worshipping a spring and stone carvings near the place of drinking water (p54). Apart from familiarizing and sensitizing students about water-related issues, textbooks at both primary and upper primary level were also found to include many real-life success stories of reviving water bodies by common people including children, in different areas of country, to cite a few examples, Bhima Sangh's successful efforts of reviving water bodies in grade 4 EVS textbook and Bhujpur story of groundwater recharge through rainwater harvesting (p201) and transformation of Alwar district into a green place (p202) in grade 7 science textbook etc.

Social Justice perspective

Textbooks at the primary level were found to incorporate social justice issues like gender and social (caste-based) discrimination, as compared to middle and secondary level. EVS textbooks have incorporated discussions around gender and social discrimination, for instance, in EVS textbook for grade 3, there is discussion on how water shortage in a village of Rajasthan, 'Bajju', impacts lives of women through a picture showing women walking long distances to fetch water for daily use (p134), and students have been asked one word questions like 'Do your neighbors bring water from the same place ?; Are there certain people who are not allowed to take water from there?; Who fetches and stores water in your house?' with the purpose to sensitize children towards issues like caste and gender discrimination (p 21); in EVS textbook for grade-4, issue of unequal access to water is presented through an example of water park in an area (Bazaar Gaon, Maharashtra) where villagers are facing water shortage issues (p147-148). There textbooks have also mentioned other implications of water shortage and pollution like migration, health issues and extra financial burden on people etc. There are also footnotes in EVS textbooks which appeals to facilitators to discuss such issues with children to sensitize them towards gender and caste-based discrimination and sensible use of water. Though uneven distribution and differential access to water across the country have been discussed in the textbooks, human-induced causes and consequences of unequal access to safe water in terms of health effects and opportunity cost is not discussed sufficiently.

In grade 7 textbook, there is discussion on water pollution due to poor sanitation and sewage and how students can contribute in maintaining the water sources in healthy state, for example, by approaching municipality or gram panchayat to compliant about open drains and sewers (p220). However, there is no space for discussion around the people (manual scavengers) involved in the cleaning of these drains and sewers and what impact does such work has on their lives.

In grade 10 textbook, social justice issues like displacement of people and inequitable distribution of water, etc. caused by mega projects like construction of dams, are incorporated significantly; however, instead of enabling students to think critically about various aspects of these issues and explore connections between these aspects, textbook describes relatively few dimensions of such issues.

Environmental aspects related to water

The main approach in EVS textbooks is anthropocentric, the facts related to water scarcity and water pollution are discussed concerning its impact on human health, whereas, the impact on plants, different animals, and aquatic life, is only briefly mentioned at different levels., The concern for the environment seems to be arising from concern for human welfare, for instance, any attempt that has been discussed in the textbooks to deal with the water shortage or water pollution is made when human health and everyday life is adversely affected; none of the story or incidence is mentioned in the textbooks where any effort is made to save the environment for the sake of environment and well-being of other species. However, the importance of water for different species and its relation to biodiversity is discussed at primary as well as secondary level.

Whereas at the primary level, the focus is more on the water shortage, as we move from primary to secondary level, the focus shifts to water pollution. While discussing water pollution, the textbooks were found to emphasize more on the surface water pollution as compared to groundwater pollution Although textbooks have included brief discussions about the impact of pollution on aquatic life at all levels, the long-term consequences of water depletion and contaminations on the environment are not discussed. The interrelationship between humans and the environment also does not seem to be adequately addressed in the textbooks. The way water shortage is projected in the textbooks, it is attributed more to natural causes and only human-induced cause discussed is an increase in population which has exaggerated the situation; there is not much discussion around water mismanagement issues at local as well as at the national level except in the textbook for grade 10.

Social Justice perspective

Environmental sustainability is an important aspect of sustainable development. Throughout the grades, especially at primary level, textbooks have emphasized sensitizing students towards sensible and just use of water resources. However, textbooks does not provide much opportunity for students to critically think how does unjust exploitation of water resources by a particular section of the society (for example water-intensive industries like mining industry) affect the majority of people, other species and ecosystems in various ways and create sustainability issues. The issue of water management is essentially an issue of environmental justice (Vanderwarker, 2012) and everyone including the non-human species have right to environmental resources like water. This sentiment is found to be missing from the textbooks.

Economical aspects related to water

Economic development is at the heart of sustainable development. According to Adekunle (2017), a society which is economically more developed is more sustainable. The economical aspect of water is briefly discussed in EVS textbooks. In grade 5 EVS textbook, students are asked to examine the water bill printed in the textbook and find out how much do they pay for water. A few instances, these textbooks also mention that some of the people have to buy drinking water from the market as there is no provision for safe water supply. As the focus at the primary level is mostly on the use of water for domestic purposes, the economical aspect of water concerning agricultural and industrial use is not discussed. As we move to the secondary level, there is a discussion related to cost involved in mega projects like the revival of river Ganga.

You must have heard about the Ganga Action Plan. This multi-crore project came about in 1985 because the quality of the water in the Ganga was very poor (NCERT, 2006, grade-10, p266)

The economic value of water in producing hydroelectric power is also discussed in science textbooks for grade 9 and 10. These instances help make students realize that the water that is supplied to their houses and communities is not free as contrary to popular belief, but it is paid, as there is processing cost involved. However, it is not mentioned in the textbooks that this cost differs from domestic to agricultural and industrial use. There is also no discussion around ‘subsidy’ provision, what it is, and how it varies for water consumption for different purposes.

Social Justice Perspective

The textbooks of secondary level have incorporated social justice issues that are related to economical aspect of sustainable development, for example, while discussing the mega projects, textbooks at the secondary level address the issues like inequitable distribution of water from the dam, woes of people who are displaced from the site etc. The textbooks for primary and upper primary level were also found to address social justice-related issues like the struggle of people from marginalized section to arrange water for daily use and helplessness in using dirty water for various purposes including drinking, whereas people from a privileged section of society have easy access to water and water purification systems.

CONCLUSION

The analysis revealed that sustainability and social justice perspectives are incorporated significantly in EVS textbooks for primary level and to some extent in science textbooks for secondary level. Whereas science textbooks for upper primary level seem to adopt factual approach and marginalize the sustainability and social justice perspectives. Additionally, at all levels, the contentious issues that arise because of the complex interaction between human and environment are not adequately addressed. The discourse on misuse and mismanagement of water resources for industrial as well as agricultural purposes is side-lined in the textbooks. For example, cultivation of water-intensive crops in areas with low water table, constructing industries which require a large quantity of water in areas facing water shortage issues, violation of rules and regulations related to waste discharge are not adequately covered in the textbooks.

There are very few instances where students are provided space to think critically about issues related to sustainability and social justice; they are asked closed questions with limited scope for critical and interdisciplinary thinking. There is a need to create space for students within the textbooks to understand and appreciate the complexity of human-environment interaction and reflect on their experiences as a member of the society from a sustainability and social justice perspectives.

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BUILDING A "TECHNICAL CULTURE": EXPERIENCES OF ENGINEERING STUDENTS IN A TECHNICAL INSTITUTE

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This paper seeks to discuss how engineering students' aspirations and professional identities are shaped by the broader neoliberal and patriarchal socio-political structures that they are part of Employing in-depth interviews of six engineering undergraduate students and discussion threads in social media, the paper discusses students' attempts at building technical identities in an educational system that privileges self-motivated learning. Students allude to the deteriorating "Technical culture" in the campus as a hindrance to the development of their technical capabilities. While the article documents how they define the notion of "technical culture", it is striking that the technical culture is especially alienating to women. When it comes to learning, students view the university as a hindrance to and not a facilitator of learning and devise their own strategies to learn-these are documented and interpreted in the light of literature that discusses the impact of neoliberalism on education.

ENGINEERING EDUCATION IN INDIA: STATE OF THE ART

The Nehruvian imagination of postcolonial India positions technoscience as a central actor in the path to modernisation and development (Nandy, 1988). Post-independence, the state invested heavily in science and technology based development projects. Science and engineering thus came to acquire respectability as professions, but were not necessarily seen as lucrative professions, in the manner in which they are viewed today. It was in the 1990s, following liberalisation, that many of the regulations that controlled Indian businesses and foreign enterprises were dissolved and the private sector began to tighten its clutches on the Indian economy.

Engineering as a coveted profession of the middle classes needs to be understood in this context (Khandekar, 2013). The middle classes in India, according to Khandekar (2013), came to pin their hopes on neoliberal-reforms' professions because of a unique set of historical reasons that pitted them against the state. This, along with the unique status that technoscience has always occupied in the vision for development, vests within science and engineering the 'the promise of modernity'.

Modern engineering education of an institutionalised nature in India can be traced back to the colonial era of the 18th century. Since then, the number of engineering education institutions have grown gradually till the latter half of the 20th century. However, it is the 1990s that witnessed a tremendous growth in engineering colleges (Subramanian, 2015). This period ushered in an increased investment in professional education by the private sector (Srivastava, 2007). Kapur and Mehta (2004) note: "the private sector, which accounted for just 15 percent of the (engineering) seats in 1960, now accounts for 86.4 percent of seats (and 84 percent of all engineering colleges)" (p.6).

However, the quality of these institutions remains suspect. A very small proportion of engineering graduates are considered employable by prospective employers and only a handful of the engineering institutes in the country are considered to be of good quality (Varshney, 2006). The National Employability Report (Aspiring minds, 2016), for instance, which presents a study of the employability of fresh Indian engineering graduates in relation to IT roles, engineering roles and non-technical roles reveal worryingly low levels of employability. Alongside this, the job market is shrinking (Siddiqui & Sharma, 2017). This is perhaps a major reason, along with other social hierarchies prevalent in elite institutions that severe depression among professional college students is reported (Ghosh, 2018). Of late, there have been several media reports of student suicides in top engineering institutes. All of this points to a crisis within engineering education as well as the engineering sector, despite efforts on the part of the government to launch campaigns such as Make in India and Start-up India[1].

THE POLITICAL ECONOMY OF ENGINEERING EDUCATION

Engineering practices and institutions need to be understood in relation to the broader political economy, which, in the present context is overdetermined by neoliberal structural policies. Neoliberalism is a political ideology that emphasises greater freedom of the market, withdrawal of the state from the public sector and subsequently its welfare functions (Carter, 2008). Thus, competitiveness and individualism become acceptable human conduct, which, in the educational context, translates to the learner being expected to "take responsibility for their learning throughout their educational career while showing an adaptable approach to job seeking and reskilling in an employment market characterised by uncertainty and career instability" (Patrick, 2013, p.3). Knowledge comes to be viewed in a utilitarian sense and learning gets equated with the acquisition of 'skills' which can be measured through standardised assessment measures.

It is within this overall scenario that the reported study is being conducted. It seeks to examine the ways in which students reflect the anxieties that are an outcome of the socio-political context presented above and the ways by which they anticipate and negotiate the uncertainty of an educational system that is built on the aforementioned principles.

METHODOLOGY

The study is being conducted in a private engineering institute which, as per the National Institutional Ranking framework (MHRD, 2018), falls within the top 20 engineering colleges in the country. Students are admitted to the institute based on their performance in a national eligibility test. The students hail from fairly

[1] These were launched to boost the manufacturing sector and entrepreneurship respectively.

privileged socioeconomic backgrounds[2] and the men students (82%) outnumber the women students (18%). The model of education within the institute follows the principle of self-motivated learning wherein students have the option to not attend classes and learn on their own. The primary inspiration for the study came from a meeting that the author of this article and a co-researcher attended in March, 2019 wherein students' academic and non-academic issues were discussed. Many students spoke eloquently about the academic culture within the campus. Among others, they talked about inadequacies in the "technical culture" extant in the campus as well as the necessity to hone their "skill sets" to increase their employability. They lamented about the lack of drive and the rising mental health crisis among the students.

In the aforementioned context, our research objective is to understand the ways in which students negotiate their professional educational experience in a system where maximum "freedom" and "choice" is afforded to students to learn and innovate. The time spent in the institution is also a period of time wherein they "come of age" and become solely responsible for their future professional trajectories, which places immense pressure on them. The study can be methodologically placed within the interpretive research tradition and involves data collected through in-depth interviews (of about an hour each) of six engineering undergraduate students[3], as well as analysis of online blogs and discussion threads on social media. The latter were shared by the participants themselves to shed further light on specific concepts that were discussed in the interviews.

PARTICIPANTS

The six students whose interviews are presented here are Akash, Suraj, Ankit, Asha, Seema and Shreya (refer to Table 1 for their profiles). Four of these students were present in the initial meeting that discussed technical culture in the campus and were articulate about their views. The six cases represent i) different areas of specialisation ii) differences in 'techie' identities and iii) different genders. Among the men students, Ankit seems very much a techie, being inclined towards research and development within his domain, while Akash and Suraj have chosen to steer away from engineering into management and finance. Among the latter two, Suraj appears to move seamlessly between techie and management identities, which is evident in his discussion about the various roles he has taken vis-à-vis various technical projects on campus. Among the women students, Asha has chosen to move away from engineering to social sciences, having done excellently in her humanities and social sciences electives. Shreya, at the time the interview was conducted was in a state of confusion regarding what she finds interesting in her engineering branch and was still figuring out what she wanted to do. She had just completed an internship with a start-up in Bangalore and had found the experience useful. Seema has already completed her degree and is working with a non-profit organisation in Karnataka. Her job profile in the organisation is non-technical in nature. She was invited to participate in the study after the researchers came across a Facebook post of hers (from her student days at the institute) regarding the lack of technical culture among girls on the campus.

2 According to the data on socioeconomic profiles shared by 71% of the students, the parental annual income of 34% of the enrolled students exceed 10 lakh Rupees per annum. 13% earn 6-10 lakhs, 11% between 3-6 lakhs and 7% between 0-3 lakhs. 87% of the enrolled students hail from the general caste category.

3 The study is currently in its preliminary stages and we adopted a snow ball sampling strategy. We intend to interview more participants who would reflect diversity in terms of gender, caste and class. While this article was being written, only a few participants were interviewed

Participant (pseudonyms)	**Age**	**Specialisation**	**Parental income per annum**	**Caste background**
Akash	20	BE Manufacturing Engineering	10 lakhs	General Category
Suraj	20	BE Electronics and Electrical Engineering	10 lakhs	General Category
Ankit	23	Integrated MSc/BE degree in Physics and Mechanical Engineering (5 year course)	10 lakhs	General Category
Shreya	19	Electronics and Communication	10 Lakhs	General Category
Asha	20	Electronics and Communication	10 lakhs	OBC
Seema	24	Electronics and Instrumentation	10 lakhs	General Category

Table 1: Participants' profile

RESULTS

Students reveal tendencies/aspirations that are circumscribed by the neoliberal as well as patriarchal socio-political context within which their education and profession is embedded. This is evident in their motivations for choosing engineering, their concerns about 'skill sets' that are required to be employable, their disinterest in academic learning, and in their articulations of how they wish to shape their careers in future. However, at the same time, they are agentive and wish to bring about changes to their predicament, which they characterise as alienating. In the following section, we discuss these aspects.

a. Motivations for choosing engineering

Among the six participants, Akash chose engineering because it is a "family thing": there is no engineer in his family. Seema, Shreya, Asha and Suraj also mentioned aptitude in mathematics and sciences as a reason. Suraj mentioned engineering being a "safe option" as a reason for his choice, since opting for the arts or journalism can make it difficult to get placed. All participants except Ankit mentioned that they did not actively chose engineering, and that it was a practical decision, in part guided by their parents. Unlike others, engineering was Ankit's career choice since the 9th standard. His father owned a manufacturing company and wanted him to study mechanical engineering in order to expand the family business. However, in his discussion of why he chose mechanical over computer science too, we see the notion of security (with regard to job security in the event of an economic meltdown) invoked. In sum, all six participants' discourses reflect the typical middle-class Indian mind-set that views engineering as a "safe" and respectable profession for the academically bright.

b. Technical culture

As mentioned, a recurring term that surfaced in the meeting was the notion of the "technical culture". Most students mentioned the necessity to build a technical culture and the lack thereof in the campus. They shared concerns about how, for most students, life was only about partying and college fests. Ankit, in his interview mentioned that this concern goes back to the year 2016 and shared a Facebook discussion on the matter from a students' Facebook group[4]. The post captures the angst regarding the perceived absence of a technical orientation among students:

[…]

> If tech has been woven in your past, present and future #WeNeedToTalk
> If you have ever been enthusiastic about some tech project but never followed through #WeNeedToTalk
> If you think that our technical culture is not good enough #WeNeedToTalk
> If you want to be part of the solution rather than the problem #WeNeedToTalk

(Dated: 27 March, 2016)

In the interviews, the participants were probed regarding how they understood the term. A technical culture for Akash is a vibrant campus where technical projects are executed. For Suraj, the technical culture of a campus indicates how well a campus knows and is good with its technology. He went on to elaborate that most people on campus were only interested in placements and were not interested in "giving back" to the campus. He discussed the successes and travails of a project that he was involved in which aimed to make the entire campus "smart", through the development of a web-based app. These included the development of services such as a cashless system for money transactions on campus, a bus tracker that would help students on the campus access the bus conveniently and other platforms that would help make life smooth on campus. However, he lamented that the freshers on campus were reluctant to learn web development and coding from the seniors, the former only being concerned about placements.

Ankit too believed that students in the campus were disinterested in immersing themselves in projects, and that they execute projects merely to put them on their resume. For Ankit, apart from hands-on projects that would involve making something in the campus, having fun needs to be an integral part of a vibrant technical culture: "So problem solving and just doing *something for the fun* of it is part of technical culture for me…not just making robots and all that (emphasis added)."

When it comes to the women students and their perceptions of technical culture, Seema's Facebook post is self-explanatory:

> I had this thought running through my head about the Technical culture of the campus, specifically, the plight of the Girls' side of the scenario. It is abundantly clear that the percentage of Girls involving themselves in the Technical Activities is very low compared to Boys. I have been wanting to start working in the fields like Robotics and Web-Dev but the problem is that there is a lack of a specific type of motivation. There is no denying that watching someone work is enough motivation to carry-on. But girls don't have an active environment of this sort where they can go to each other, inspire, get inspiration and learn. Yes, we can do so with the Boys but it is not always comfortable for everyone to go to a completely strange guy and try to learn from him. There are no gender issues but there is no denying that the comfort level varies. I know a few girls who want to do the same but there is no such community and so, there has been no real advancement. So, hereby, I want to propose that the

4 The posts were sourced from a student only Facebook group. Permissions were obtained from the moderators to use the posts pertaining to technical culture without disclosing the identity of those posting.

> girls who want to participate in the Tech-activities join hands by forming an informal group where we come together and work for Projects. Interested girls please comment and based on the response we can proceed further. Please tag the girls you know who would want to join this cause and also, put-in your thoughts about the way we should go with the whole process. (Dated: 27 March, 2016)

When invited to provide more context on the post, Seema shared that a technical culture on campus was absent among the girls since they do not team up and work together. She lamented about the lack of inclination among girls (unlike the boys) to get together and make things. She also mentioned how a lot of informal technical projects were executed by the boys in their hostels which did not happen in the girls' hostels. Furthermore, she mentioned instances wherein she and other girls faced sexism when working with boys. Asha believed that even when the boys are not sexist, they do not perceive women as "one of their kind" to actually work with them. She believed that girls were also more "academic" and individualistic in their approaches to learning. Shreya believed that the sheer fact that the boys out-numbered the girls makes it difficult for the girls, and the existing socialisation patterns in society forbade the opposite sexes from mingling with one another, making it difficult to learn from each other.

c. Skill sets and knowledge

Another phrase that the students used in the faculty-student meeting was the lack of "skill sets" among the students and the need to develop these. In the interviews, we specifically asked participants what they understood by the term. Akash believed that a, "Skill set defines how employable a person is, how flexible or versatile as a person is." Ankit and Suraj did not define "skill set" clearly…but acknowledged that these vary from domain to domain. Both Akash and Suraj believed that learning coding and basic programming are important skills that make one versatile and employable in the job market. Shreya, Asha and Seema were not specifically probed on what they understood by skill sets as they were interviewed later and by then we had realised that students seemed to hold convergent views on what they understood by the term.

d. How to learn

A question that was asked of the participants in the interview was how they go about acquiring the "skill sets" that they deemed missing among students in the campus. All six students believed that skill sets need to be acquired by immersing oneself in a hands-on project that addresses a real-life situation. Akash, for instance, talked about how he learned management and people skills simply through heading the language activities club on campus. Suraj believed that skills can be picked up by immersing oneself in projects that "give back to the community". On probing further, we came to understand that for him the "community" was the campus. He also talked at length about mentoring and learning in the context of discussing the smart campus project. His learning from the entire experience was that the freshers do not learn unless there is a financial incentive. Ankit also echoed the idea that giving back to the community is an important context for acquiring skills. For him, knowing what skill sets to acquire is possible by approaching the seniors. He also believed that learning happens if there are penalties built into the learning process. It is interesting that both Ankit and Suraj held behaviourist models of learning. When probed further about how to acquire skill-sets, Suraj talked about online certified courses, asking seniors, and only finally, the faculty and coursework.

A similar disengagement with academics and coursework was true for both Ankit and Akash as well. Ankit said that he attended classes only if he is "not occupied with something else". Yet, he believed that keeping "in touch" with professors is important, particularly when executing projects. Akash mentioned that his attendance of the courses offered by his branch (manufacturing) were low because they were repetitive and redundant and he had lost interest in them over time. Shreya, Asha and Seema also revealed a similar perception of disinterest in academic courses. Both Shreya and Seema also talked about learning things online.

All the men participants unequivocally acknowledged tremendous support from their seniors, – or *bhaiyyas* as they reverentially referred to them – in navigating their student life on campus. Akash talked at length about how supportive his seniors have been in terms of hand-holding him through the initial few semesters at college, be it advice about how to manage his CGPA or how to prepare himself for placements. Suraj mentioned the vital role that his seniors played in initiating smart-campus and how they inducted some of his friends, getting them to develop the app and the webpage. It is striking that an analogous woman senior was completely missing in the women students' narratives.

e. What does being a "good engineer" constitute?

The participants were all asked what comes to their minds when they hear the word "a good engineer". For Akash and Seema, a good engineer has good knowledge and the skill to apply it and should be able to innovate things in a way that life gets better for people For Akash, consistency and the willingness to work hard marked a good engineer while for Shreya, it is someone who "gets the job done" creatively. For Suraj, a good engineer is someone who gives back to society, while making profit ought to be a secondary thing. Ankit was unable to define a good engineer, but seemed to think his uncle was one. He believed that an engineer has to be knowledgeable in many areas and capable of systems thinking. Asha too believed that a sound knowledge of science is necessary to be a good engineer. It is interesting that both Seema and Shreya used the word "he" when referring to their conceptualisations of a good engineer.

DISCUSSION

As discussed, the nature of the privatised engineering education that students receive is by and large circumscribed by neoliberal economic processes. This is evident in the principle of self-motivated learning that the institute advocates, wherein complete autonomy is offered to the learner to drive their learning.

Building a technical culture, for the students, is a response to the increasing levels of alienation that they are witnessing on campus which is a direct result of the individualised, self-directed and competitive learning environment they are part of. For the men students, the idea of "giving back" to society or the campus through technical projects figured prominently in their articulations. They believed that engaging in these projects makes one feel rooted, connected with other individuals and their profession. However, it is important also to critically interrogate the idea of "giving back", does this concept encompass notions of social and environmental justice? Our preliminary exploration suggests otherwise. Furthermore, our preliminary investigation reveals that core of the "technical culture" is gendered and patriarchal – in the fact that it is exclusive of women and probably other minorities.

When talking about how neoliberalism has reconfigured teaching-learning, Patrick (2013) writes, "Within the new language of education, the teacher is there to meet the needs of the learner, but these needs are narrowly defined as "learning" needs within a model that reduces learning to a series of teaching inputs designed to meet pre-specified outcomes" (p.4). This view of learning is especially evident in all the students' articulations when they seemed to suggest that course work and the role of the "profs" is only required on an "as-needed" basis. This points to a deeper and graver question of whether under the new scheme of things, a teacher is needed at all.

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FROM *CHARANAMRIT* TO *GANGAJAL* VIA BRINDAWAN-MATHURA-KASHI: CULTURAL POLITICS OF WORD-PROBLEMS IN SARASWATI SHISHU MANDIR MATHEMATICS TEXTBOOKS

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Textbooks are the prime source of knowledge in Indian schools. They occupy sacrosanct status particularly due to memory-based examinations. They are used not only as artefacts of learning but also as carriers of values, beliefs and ideas, particularly of dominant classes. Compared to textbooks of History or Language, those of Mathematics or Physical Sciences are perceived as 'objective' and therefore 'harmless' in the context of social inequalities. In this paper, I attempt to analyse word-problems from Mathematics textbooks of Saraswati Shishu Mandir (SSM) to unpack the structures and layers of gender, caste and class domination. I show how SSM textbooks are overtly prejudiced and argue that contexts presented in word-problems should be locally relevant but without bartering away progressive social outlook.

TEXTBOOK-CENTRIC SYSTEM OF SCHOOLING

The fact that educational discourse in school education in India revolves around paper-textbooks (textbooks hereafter) is well acknowledged by all actors in education – students, teachers, parents, community at large and academics. Completing the syllabus usually means 'finishing' the textbook from cover to cover, and success or intelligence means memorising textbook in verbatim. Textbook-examination nexus has survived all policy recommendations against it. Krishna Kumar (2004, 36) writes:

> The examination-textbook linkage became stronger as the system of education expanded and as the stagnation of work opportunities exacerbated the competitive character of the system. The linkage defeated all attempts to reform the curriculum and the methods of teaching.

The problem is that textbooks do not offer pieces of information but what Michael Apple famously called as 'valid' knowledge that is not neutral. He reminds us that —

> The curriculum is never simply a neutral assemblage of knowledge […] It is always part of a selective tradition, someone's selection, some group's vision of legitimate knowledge. It is produced out of the cultural, political, and economic conflicts, tensions, and compromises that organize and disorganize a-people. (Apple, 1993, 222)

Students and teachers seem to 'willingly' surrender their autonomy to textbooks at the cost of pedagogical choices and methodological innovativeness. M. K. Gandhi too cautions us when he writes that:

> If textbooks are treated as a vehicle for education, the living word of the teacher has very little value. A teacher … becomes a slave of textbooks and has no opportunity or occasion to be original. It

> therefore seems that the less textbooks there are the better it is for the teacher and his pupils. (Gandhi, 1939)

TEXTBOOKS AND HIDDEN CURRICULUM

An apparently 'progressive' curriculum or syllabus can lead to choice of a text loaded with what Phillip Jackson famously conceptualised as the 'hidden curriculum'. By hidden curriculum one understands unwritten transaction and reproduction of beliefs, values, norms, ways of behaviour, or simply 'culture' through formal educational content and informal and other social interactions in a formal setting like school. In a textbook, hidden curriculum can be employed through all of its building blocks including words, images, illustrations, etc. leading to cultural supremacy and stronger socio-cultural power to some section of society, many a times the dominant class. For instance, in the 1920s, in an attempt to raise concerns of the marginalised about politics of the upper castes (formerly touchable castes) in schooling, C. S. Kate, a reader from Solapur, writes in a letter to Marathi fortnightly *Bahishkrut Bharat*, founded and edited by B. R. Ambedkar.

> How bitter are the tongue, gaze and thoughts of the touchables!! Grade 3 Balbodh Textbook Lesson 46 – Occupations in Village. This lesson employs reviled language mentioning caste of the persons like Kusha *dhor* and Parasha *chambhar*. In school-textbooks too the bitterness of their (touchables') tongue, gaze and thoughts is prominently visible. (Kate quoted in Darak, 2013. Translation by Ms. Madhuri M. Dixit)

As evident here, hidden curriculum appears to have been used for either ill representation or misrepresentation or underrepresentation of the marginalised communities at the cost of their self-respect: a fact that is clearly acknowledged by policy documents in India that cultural politics of school-processes leads to 'Brahmanisation as key defining feature of curriculum' (NCERT, 2005 A, 24) and of schooling.

The large body of scholarship on textbook analysis suggests that usually subjects like language and history are prime sites of employing cultural politics through textbooks. Histories of textbook related controversies from across the world also converge with this view. On the other hand, it is assumed that subjects like Physical Sciences and Mathematics, due to their epistemologically 'objective' nature, leave little scope to any socio-cultural variation.

The invariance of answer in a mathematical problem or its independence with respect to the algorithm may create a 'feeling' that mathematics can be independent of context too; but word-problems may be the game-changer. Although word-problems are considered as a pedagogical tool for creating connect of 'abstract' numbers with the 'real' world, which may imply their agency in creating meaning, large body of research on word-problems focuses on utility of word-problems in helping students arrive at desirable answers, on connection between 'nonsensical' answers and wording of problems, or on link between difference in structure of word-problem and variation in students' performance, etc. But cultural politics employed through Mathematics textbooks and patterns of hidden curriculum embedded in word-problems remain underexplored.

Word-problems as a social text

Word-problems attempt to present situations closer to lived realities so that numbers and operations presented in a mathematical text can be contextualised. In doing so, they may succumb to the hegemonic tendency of presenting a particular point of view that is usually familiar to the dominant classes. Richard Barwell explains why treating word problems as texts leads to difficulties in understanding 'unrealistic' responses of students or why their responses may be related to their socio-economic backgrounds, and he argues that "word problems need to be understood as social texts. Early research on students' performance on word problems generally treated them as mathematical texts or, at best, linguistic texts." (Barwell, 2018, 117). If we examine word-problems as social texts, they can be analysed for different aspects of societal relations including ideology, patterns of marginalisation and subordination as well as ways of exhibiting social power. With this outlook in place, Mathematics textbooks may also be treated as a cultural artefact instead of merely a pedagogical tool.

Research in mathematics education focussing on word-problems alerts us to this nature of word-problems. Words, pronouns and phrases used in word-problems, artefacts and goods shown to create real-life situations may create a different meaning in the mind of a learner depending on her socio-cultural background and is a function of 'cultural capital' in Pierre Bourdieu's terms. Designer of a word-problem may come from a different experience of life than those of learners leading to some intrinsic prejudices coded in the words of a word-problem and also in imagining a desired, correct answer. A context which is apparently neutral or value-free may also turn out to be a prejudiced one due to engagement of learners with the situation described in the word-problems. A famous example discussed in scholarship in the field is – It costs $1.50 each way to ride the bus between home and work. A weekly pass is $16. Which is a better deal, paying the daily fare or buying the weekly pass? Tate (1994) argued that the problem designer implicitly assumed that people work for 5 days a week and that one person has only one job ignoring possibility of people working on weekends too and having more than one jobs. This lived reality was imposed on the "neutral" situation by the African American students and led them to choose the 'wrong' answer as 'weekly pass'. The solution was economically prudent and mathematically logical for these students. Such integration of real life situations can be argued to be superficial or be seen as an act of tokenism because the more important question – *whose real life experiences* – is brushed under the carpet. While discussing the idea of 'humanising students' Mathematics curriculum' in the context of unban students, Ukpokodu (2016, 134) cautions us about 'integrating superficial content' in word problems that 'trivializes and stereotypes urban students' lives and their communities.' With appropriate examples of word-problems she discusses how some of the teachers may consider some word problems as intending to be 'culturally responsive' but may end up stereotyping the community as drug addicts or dealers.

Schools across cultures consider textbooks as tools of establishing structural superiority of one class over the other and therefore may show clear tendency of choosing texts that are 'suitable' to their ideology. In her brief but engaging story of Chinese schools in Calcutta, Zhang Xing (2010, 53) describes how in the 1950s and 1960 schools aligned to pro-Guomindang faction (for example Meiguang School in Calcutta) considered textbooks provided by People's Republic of China not appropriate "due to very different ideology" and it explains "how ideological differences in regard to textbooks became a political issue at the Peimei School."

Even though ideological moorings are common to social enterprises, Mathematics textbooks cannot be left outside socio-cultural analysis while unpacking the ideological framing. Research about mathematics textbooks from different cultures reiterates this fact. For example, Anjum Halai (2007, 114) describes mathematics textbooks in Pakistan as carriers of tasks describing –

> [S]ituations which would be culturally regarded as the domain of males. For example, in an exercise of ten word problems, there would be eight word problems favouring boys through reference to their favoured profession and through mentioning male names. This was found in most textbooks whether published by local private publishers or those publishing for the textbook boards.

Thus descriptions in word-problems in mathematics textbooks should also be seen as "'valuative selections' from a much larger universe of possible knowledge and collection principles" and they must be probematised "so that the social and economic ideologies and the institutionally patterned meanings that stand behind them can be scrutinized." (Apple & King, 1983, 84).

WORD-PROBLEMS – EXAMPLES FROM SSM TEXTBOOKS

Following sections discuss the ways in which word-problems can be employed to create a cultural discourse in India. By exploring subtle as well as overt biases I argue that word-problems in Mathematics textbooks can also be used as tools for dishing out certain type of world-view as a valid or official view.

My examples are from elementary grades from textbooks published by one private publication: Sawaswati Shishu Mandir (SSM). They are used by schools established by Vidya Bharati, an outfit of Rashtriy Swayamsevk Sangh (RSS), a right-wing organisation believing in supremacy of Hindu (read Brahman) culture and working towards universalisation of the same. Ideologically the SSMs attempt to build Hindutva (read Bramanism) as a practice among the rural masses. Over the past 70 years since early 1950s, about 25,000 SSMs and similar schools are opened and run by the Vidya Bharati in an attempt to capture the vacuum created by failure of the state to provide schools for children, particularly marginalised children in rural India. Some studies have shown that the discourse of SSMs through their textbooks as well as their daily conduct is highly prejudiced against feminine genders (Chauhan, 2011, 2012) and teaches hatred (Sundar, 2004). But the textbooks chosen for analysis by these scholars are language and history textbooks. With examples of some word problems from grades III, IV and V textbooks, my attempt would be to raise issues arising in 'inclusion of local contexts' and 'lived experience of learners', since National Curriculum Framework 2005 suggests incorporation of "local knowledge and traditional skills, and a stimulating school environment that responds to the child's home and community environment" (NCF, NCERT, 2005 B, ix).

As stated in the preface, the publishers of the textbooks published in 2008 by Saraswati Shishu Mandir Prakashan, Mathura, believe that "Mathematics is the basis of transactions in our life, art, knowledge and science. The key to proliferation of knowledge in science, computer or nuclear weapons lies with Mathematics. But due to lack of interesting style (of presenting and teaching) children consider learning important subject like Mathematics as most complex and difficult." These textbooks of grade 2 to 5, as the preface states, are developed to make mathematics more interesting by "a group of SSM teachers after adequate engagement with and deliberation on (the topic).” My analysis treats word-problems as social texts that play a role beyond merely presenting a mathematical problem statement to learners.

HINDU GODS, HINDU DEVOTEES

In an attempt to teach concepts of Operations with Metric Units, textbook of grade IV gives the following problems.

1. Height of temple of *Radhaji* (companion or confidant of Lord Krishna) is 143 m. 50 cm. If height of one step is 35 cm, how many steps one needs to climb to go to the temple? (page 88)
2. Virndavan Rangji temple has a pillar made up of 250 kg. 680 gm gold. Dwarikadhish temple of Mathura has golden cradle weighing 200 kg 800 gm and tower of Kashi Vishwanath temple is coated with 251 kg 350 gm of gold. What is the total amount of gold in the three temples? (page 87)
3. Indra’s vehicle is *airawat* (elephant) and Ganesha’s vehicle is mouse. The weight of mouse is about 750 gm and that of the elephant is about 10 quintals then how many times is the elephant heavier than the mouse? (page 91)

It can be argued that visiting temples and worshiping gods is a routine experience for children. But it is not highlighting of everyday practices of the tribal communities whose children attend SSM schools in large numbers. Names of the Hindu deities, the mythic characters – Radhaji, Rangji, Dwarikadhish, Vishwanath, Indra and Ganesha – appear as real-life characters. But the ‘lesser deities’ of the tribal children do not find any mention. The word-problems not only appear to rob the tribal children of their culture by keeping silent on symbols pertaining to their culture, but are also imposing upper caste Hindu deities on them. In fact, the textbooks do not acknowledge tribal communities, they call them as *vanavasi* (forest dweller), a term specifically used by RSS in its sanitising activities among tribal groups. Even though freedom of worship is a right in India, mention of only upper caste deities implies them to be a part of the ‘normative’ right.

Gender and SSM Textbooks

We consider another set of word-problems to discuss how gender is created and reproduced in the textbooks:

4. For the marriage of his daughter, Ramendra took loan of Rs. 25000 from his provident fund on 7th March 1999 at the rate of 13% p.a. He repaid the loan on 12th October 1999. What is the amount of repayment? (grade V, page 74)
5. 426 brothers and sisters learn in a school out of which 142 are sisters. what is the ratio of brothers to sisters? (grade V, page 73)
6. Geeta and Seeta met in the temple. Geeta told Seeta that she would visit the temple on every second day on the same time. Seeta said that she would not be able to make it every second day but would visit the temple every third day at the same time. If they met in the temple on 31 August for the first time, on which days would they meet in the month of September?

Throughout the textbooks all children receive a peculiar mention as *bhaiyya* (brother) and *didi* (sister). Children as young as 6 to 11 years old are never imagined as friends or simply boys and girls. It indicates that these textbooks have a peculiar tendency of permitting only a ‘pious’ relationship between opposite sexes, even though the same textbooks celebrate Krishan and Radha who, according to the same mythological stories, shared a relationship outside their marriages.

Usually, a problem discussing about borrowing and lending at some interest rate could think of many situations in which such monetary transactions take place. But the textbooks borrow for ‘marriage of a daughter’. It subscribes to a prevalent thinking that marrying the daughter is a responsibility of the father (and as a flip side, controlling her sexuality is his right). Moreover, even if one is debt-laden, one has to marry one’s daughter observing minimum standards of celebration. Marriage and dowry are two important reasons why daughters are considered as *boz* (burden) in families in the Indian psyche. The SSM books simply strengthen this thinking by creating such situations in the word-problems.

Another and more interesting story is that of Seeta and Geeta (problem 6 above). It is used to teach LCM and the calendar. In all the SSM textbooks of Mathematics, women and girls are rarely present in word-problem and if they are, they are largely confined to domestic spheres performing the ‘traditionally acceptable’ roles for women. If at all they move out of their domestic limits, they go as far as the temples or on pilgrimage as good devotees. At best they may go to buy groceries. Word problems on profit-loss, interest, ratio-proportion clearly indicate that women and girls do not get involved in any meaningful financial transaction neither do they own any property or goods. All transactions involving money (be it selling cows or lighting some temple or borrowing money from bank) are restricted to the masculine gender. The only scholastic activity women do even within their domestic confinement is reading certain pages of holy texts like *Ramayana* or *Bhagavdgeeta*. The textbook girls and women possess high moral character, remain chaste especially if they are devotees of upper caste Hindu gods and spend their lives performing *seva* (service) of gods and men-folks. Such confinement of women to domesticity and their limited exposure to external world only in the form of temples and pilgrimage severely restricts entry of ‘real’ women from ‘real’ world in the textbook. Even if visiting temples and traveling for pilgrimage is a part of lived reality of women and girls in the local milieus, there are major other lived experiences that are completely ignored. Women in the geographies where these textbooks are circulated are involved in large range of labour-based activities outside their domestic worlds. These include farming, hunting, working on construction sites, milking domestic animals including buffaloes (not only holy cows, a favourite animal of these textbooks), managing small shops, teaching, nursing, and so on. On this background the selection of only particular type of experiences neglects their knowledge, skills, labour, ownership, and meaningful transactions. Such selections become further problematic considering that the tribal children come from families that may not be soaked completely in patriarchal ideology as the textbooks are.

This analysis, juxtaposed with aforementioned analyses by Chauhan (2011, 2012), Sundar (2004), clearly establishes the misogynistic nature of SSM textbooks. Textbook ignorance of existing higher levels of gender equality among tribal societies which is actually a lived reality for children and its imposition of Brahmanical patriarchy even in the most ‘objective’ of the school subjects, amounts to setting up a clear example of hidden curriculum. It is coherent with the overall project of the right-wing. Ironically, it coincides with the agenda of textbooks from Pakistan (Halai, 2007), the ‘perceived enemy’ being used by RSS and SSMs to build a ‘Hindu Nation’.

HINDU WAY OF LIFE – THE PRESCRIBED NORMATIVE

The textual persecution of multicultural reality of India becomes severe when upper-caste Hindu practices appear with meticulous details for all kinds of learners in these textbooks. Consider the opening paragraph on page 87 of grade V textbook. The chapter is meant for teaching Traders' Accounts.

7. Description of trade rituals (*Vyapaar Vidhi*): On an auspicious day, the first thing to be done is to draw a picture of the deities Ganesh and Laxmi and write the holy chanting on the accounts book and then to worship it. Then credits will be written everyday on the left hand side and the debits will be on the right hand side.

It is clear that the very first line of the above description does not have any connection with the accounts one would write 'mathematically'. Such descriptions of sacrosanct status are meant for prescribing 'normative culture' through textbooks and are meant to show 'correct' ways of life, thereby establishing supremacy of dominant cultures. This description reminds me of the work of Julia Kwong (1988) on Chinese mathematics textbooks. With the help of suitable word-problems Kwong discusses how Chinese Mathematics textbooks, particularly from the late 1960s to early 1980s, were sites of dishing out political ideology rather than being mathematical artefact or instruments. For example -

> The proletariat revolutionary faction in the Red Flag Printing Company was filled with the proletariat love of Chairman Mao. As a part of their contribution to their national day celebration, they enthusiastically printed pictures of Chairman Mao. They printed 4392 copies in the morning and 5608 copies in the afternoon. How many could they produce in one day? (Textbook of Mathematics of 1969 quoted in Kwong, 1988)

Irrespective of the concepts to be taught, the SSM textbooks show high tendency of detailing only upper caste Hindu practices. We may observe how the problem of simple addition of liquids comes in through the route of a temple or home based institutionalised practice of worshiping Hindu gods. Consider the following problems.

8. 200 litre milk, 5 litre honey and 10 litre *gangajal* (holy water of river Ganges) were used to make *panchamrit* (holy mixture of 5 liquids 3 of which are derived from milk of Holy cow) on the day of Janmashtami (birth day of Lord Krishna). If 50 litre curds and 10 litre *ghee* (clarified butter) were used, what was the total quantity of *panchamrit?* (grade IV, page 92)
9. Ekata sister's mother (Ekta *bahin ki mataji*) prepared 2 litre *charanamrit* on the day of Janmashtami. She used 300 ml milk, 100 ml honey, 150 ml curds and the rest *gangajal.* How much *gangajal* did she use? (grade III, page 93)

The above problems carry an intrinsic assumption that all teachers and learners know what *charanamrit* or *panchamrit* is, and they even have the knowledge of its recipe. Such normative assumptions appearing in the prime source of 'valid knowledge' called textbooks, lead to assertion of superiority of the culture that follows such practices. Coming to think of reception of such problems, it is possible that learners from marginalised sections including tribals may not be aware of the cultural 'context' of the word-problem. They are put to disadvantage as they need to learn both the context and the mathematics incorporated in it. For instance, in domestic settings the *charanamirt* is usually prepared by the mother; but in example no. 8, the subject is not present and the volume of *panchamrit* suggests some other setting. The proper names of girls used in examples always have an epithet *bahin* (sister), as found in example no. 9 above, which teaches learners that all girls are sisters, particularly of the school-going boys. As discussed earlier, it appears that inter-personal relations like friendship between opposite sexes is forbidden in the textbooks of SSM.

Word-problems describing religious symbols of upper caste Hindus appear so frequently that one can sense an agenda of prescribing 'Hindu way of life' as the only 'worthy' way of life. These symbols are primarily related to unquestioned devotion to god, religious texts, religious practices and rituals.

10. Distance from Hathras to Mathura and Mathura to Vrundawan is 36 km 450 m and 10 km 170 m respectively. Suresh *bhaiyya* (elder brother Suresh) went from Hathras to Vrundawan for *darshana* of Banke Bihari (bow before god Banke Bihari). How much distance would he need to travel? (Grade IV, page 83)
11. The book of Ramayana contains 1272 pages. If Rohit's mother (mataji) wants to finish reading Ramayana in 12 days then how many pages should she read every day? (Grade III, page 58)

The task of adding distances or division of 4-digit number by a 2-digit number also requires reference to places of pilgrimage or holy texts of upper-caste Hindus. If one claims that the names of 'real' places are mentioned in problem statement 10 above, shouldn't the distances also be 'real'? Nowhere in India are distances between two towns measured to an accuracy of 10 meter. Moreover, the problem can talk of real places but why would the reason of travel be Banke Bihari's *darshan*? Can Suresh not be simply Suresh, without the imposed brotherhood through the word *bhaiyya* and travel between these places without visiting Banke Bihari? Can Rohit's mother not read any other book, for getting information, knowledge or sheer entertainment with a target of finishing it in certain number of days? Is it necessary to tie her ability to read to devotion, to surrendering to a religious symbol?

MILITARISATION AND *SANSKARI* HINDU PURUSHA

Other popular choice of contexts in SSM Mathematics textbooks is contexts related to the military. One finds problems of division based on deploying soldiers on border to respond to an attack, deporting soldiers from one place to another, etc. appear as 'normal' contexts. Descriptions surrounding the actual arithmetic in the word-problems have plenty of cultural references that point in the direction of a Hindu nation. The cultural world minus the maths in a maths text book is a homogeneous nation. The calculations children are supposed to make are meant to calculate amount of *prasad* (holy food) distributed after worshipping idols, to understand how the rituals around new account books of Hindu traders are performed, to underline the stereotype and highly patriarchal family by computing expenses for sister's marriage, sum up total number of devotees visiting Kumbh Mela, and so on and so forth. The objects taken for calculations have a religious meaning for instance, cows, pages of Ramayana, frequency of visits to the temples, flags. If a floor is to be remade, it would be in the temple of the deity Hanumana. If a woman (read mother) is preparing some food item, it would be for offerings to the god. The women would piously observe Brahmanical Hindu traditions and rituals.

It is clear that Indian values and traditions are equated with values and traditions of upper-caste males by RSS and its allies. As SSM proclaims it (SSM, 2019) –

> The child is the centre of all our aspirations. He is the protector of our country, Dharma (Religion) and culture. The development of our culture and civilization is implicit in the development of the child's personality. A child today holds the key for tomorrow. To relate the child with his land and his ancestors is the direct, clear and unambiguous mandate for education. We have to achieve the all-round development of the child through education and sanskar i.e. inculcation of time honored values and traditions. (SSM Website: http://saraswatismp.com/about-us.php)

DISCUSSION AND CONCLUDING REMARKS

Molefi Asante presents a concept of centricity which means "a perspective that involves locating students within the context of their own cultural references so that they can relate socially and psychologically to other cultural perspectives." The concept of centricity can be applied to any culture. According to Adante, "for the white students in America, this is easy because almost all the experiences discussed in American classrooms are approached from the standpoint of white perspectives and history" (Asante quoted in Tate, 1998). It appears that the SSM textbooks discussed above provide such centricity to upper-caste Hindu children although such children coming from upper caste or class may not even bother to go to schools like SSM. But since the project is to develop child through '*sanskar*', SSMs that perpetually valorise upper-caste culture cannot think of the 'real' learners in their schools and their culture. Kancha Ilaiah (1996, 7) discusses in his autobiographic reflections, young learner's alienation due to cultural disconnect with content of schools.

> We (dalit-bahujans) knew nothing about Bramha, Vishnu or Eswara until we entered school. When we first heard about these figures, they were as strange to us as Allah or Jevoha or Jesus were.

Such a disconnect between the lived realities of learners and curricular content may lead to alienation among children from marginalised communities and push them into glorified traditions of the Hindus. SSMs, where "People began to send their children to these schools in preference to christian convent-schools and over so-called public schools. In Saraswati Shishu Mandirs the children could learn about their Hindu culture" (SSM Website), proclaim their agenda to use textbooks as tools of proliferation of the so-called Hindu culture which is highly patriarchal and bramhmanical in its character. Considering that these schools are not much controlled or regulated by the state, the curricular agenda itself leads to overt indoctrination and not education, even if education is imagined in instrumentalist way, leave alone what was advocated by Jotirao Phule (1827-1890) or Paulo Freire (1921-1997) as vehicle of emancipation from oppression. One wonders if there is any need to even look for the hidden agenda in SSM textbooks. In case of Mathematics textbooks of SSM, although the overarching framework is that of capitalist economy evident through the ways concepts like profit-loss, percentage, interest, traders' accounts, etc. are developed, there is no sight of even 'superficial' neutrality or modernity or attempt to shed off prejudices like many other modern textbooks of school mathematics developed for protecting interests of capitalist economies. The agenda is adequately clear – development of a *sanskari* (cultured) Hindu as against a critically thinking citizen of India.

Textbooks may be considered as passive teaching-learning materials but when children interact with them, they become active learning instruments. Thus, when students attempt to solve word-problems from SSM textbooks, what they would get even before arriving at a solution is the cultural packaging woven around the numbers. Even if a student is not able to solve a problem, can certainly grasp cultural messages like visiting temples, worshiping gods, being confined to domestic spheres (in case of female students), and so on as the desirable way of life. Considering the overall school culture in India, it is unlikely that SSMs or most other schools leave any scope for children to reject the cultural world presented formally by schools. NCF, while supporting inclusion of local knowledge and traditional skills in schools, puts a condition that "all forms of local knowledge must be mediated through Constitutional values and principles." (NCF, NCERT, 2005 B, 32). Children's Right to Free and Compulsory Education Act, 2009 (RTEA) also 'guarantees' a curriculum abiding by the values enshrined in the constitution. The irony in case of SSM textbooks is that although the word-problems are packets of regressive ideology and full of prejudices, establishing them to be 'anti-constitutional' in a legal framework is a tough task. As discussed above, one can show that the textbooks appearing in the form of word-problems are statusquoist, ignorant about cultural practices of marginalised sections (deliberately or otherwise) and prejudiced against women. There is no intent of challenging any of the prejudices, the textbooks rather try to cement the ones existing among children's minds. The problem particularly becomes intense when such textbooks are read in the light of Draft National Education Policy 2019 which advocates for schools to have their own curricula and textbooks. One possibility of what can happen in the present political scenario is foretold be the SSM textbooks.

The issue in case of word-problems is that there may be textbooks which appear 'progressive' but yet protect interests of hegemonic groups in hidden ways, paying lip service to other cultures. Bright (2017, 8) warns us against this tokenism, this "superficial treatment of "multiculturalism" that focuses on the addition of people of color" and suggests that such inclusion "may in fact be working against some of the primary goals of a socially just society by tokenizing individuals and groups without any direct movements towards challenging the shifting other aspects of the status quo."

Way Forward

I have provided examples from SSM textbooks showing how cultural prejudice is carried even in Mathematics. The problem of narratives in mathematics textbooks becomes further complicated when identifying undercurrents becomes difficult. A case in point is a recent textbook by Maharashtra State Bureau of Textbook Production and Curriculum Research, popularly known as Balbharati, an autonomous body under Department of School Education in Maharashtra. Balbharati is responsible for textbooks reaching more than 18 million children from more than 90,000 schools in Maharashtra. In recent revision of textbooks, Mathematics textbooks have adopted a style of conversation among students and teachers leading to development of various concepts. In one section of a chapter on Measurement (Grade IV, 2016) a boy goes to fetch grocery and in another section of the same chapter, another boy observed milk being served in cups. The chapter develops in the form of conversation in domestic setting and in both sections the person conversing with the boys are their mothers. The same textbook, while teaching pictorial representation of numerical information uses male faces to represent 'farmer' or 'student' which could be considered as neutral occupations. In last decade or so, word-problems in textbooks of Balbharati, have moved fairly ahead from habits of 'missing women completely' or 'confining them only to shopping', but bringing women in domestic narratives restricts the movement. Representing farmer or student as a male shows how an opportunity of challenging prejudices is missed or how prejudices are perpetuated.

With thorough analysis of 'voice' or linguistic discourse presented in mathematics textbooks through choice of verbs, pronouns and other grammatical forms, Herbel Eisenmann (2007) emphasizes the need for mathematics educators to consider deeply "the way in which language indexes a particular ideological stance" and appeals that "curriculum developers and mathematics educators need to consider more carefully what ideological goals underlie curriculum materials." As teachers and educators of mathematics, we must remember that the numbers in the word-problems may be unrealistic or irrelevant but the contexts may be real. If the contexts are not coherent to the lived experience of children and if they hesitate to challenge stereotypes embedded in those contexts or otherwise, textbooks meant to teach the so-called objective school-subject may turn out to be tools to reproduce socio-cultural inequalities. If we agree with the vision of the position paper of National Focus Group on Teaching of Mathematics (NCERT, 2005 C, vi) that "all students can learn mathematics and that all students need to learn mathematics" then we need to acknowledge that contexts presented in word-problems need to be locally relevant and progressive in their social outlook. Failure in making them locally relevant may continue perception of mathematics as the most difficult and irrelevant subject while failure in creating progressive contexts with multiple realities may make mathematics a vehicle of social inequality and subbordination. As teachers and educators of mathematics, we need to be cautious about both of them.

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Strand 2

Cognitive and Affective Studies of STME

DEVELOPING 21ST CENTURY SKILLS AND STEM KNOWLEDGE IN PRE-SERVICE TEACHERS USING MAKERSPACE

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This paper explores the use of a STEMinist Makerspace Project to promote engagement and learning of STEM content and support the development of 21st century competencies in female Indian pre-service teachers. Using a 'Makerspace Approach' these pre-service teachers participated in a series of activities: firstly, as 'students' creating their own artefact supported through a scaffolded approach by educators; then reflecting on these experiences and developing supporting questions; taking their artefact and the materials to school and using the questions to scaffold and support primary school students to create their own artefacts. Pre-service teachers reported on their increased engagement using the Makerspace approach and cited their development of 21st century competences, listing; collaboration, critical and creative thinking, problem solving and applying knowledge, as valuable to their own learning.

BACKGROUND

The Workshop, *Cross-Nation Capacity Building in Science, Technology, Engineering and Mathematics (STEM) Education* was held in the Regional Institute of Education (RIE), Bhopal, with female pre-service teachers. The pre-service teachers participated in three Makerspace-type STEM activities that provided them with opportunities to create and learn through practical experiences.

Fifty-two pre-service teachers (PST) participated in three Makerspace-type STEM activities that provided them with opportunities to create and learn through practical experiences. The focus of this paper is the evaluation of the STEM Makerspace programs, including the development of female pre-service teachers' skills, both personally and professionally, through the workshops and classroom activities. The research questions were:

1. How effective was the Makerspace Approach in supporting pre-service teachers' engagement in STEM education?

2. What 21st century competencies did the pre-service teachers identify and demonstrate as a consequence of their participation in the project?

LITERATURE REVIEW

A Makerspace Approach

Makerspaces are increasingly being heralded as opportunities for learners to engage in creative, higher-order problem solving through hands-on design, construction, and iteration (European Union, 2015). The Makerspace approach is different from a more traditional Makerspace. Traditional Makerspace has developed from a combination of online *Hackspace* (Copyright © 2016 London Hackspace Ltd.) or *FabLabs* (Copyright © 2015 Fab Foundation) and an actual physical place termed a *Place for Making* or *Makerspace* (Smith, Hielscher, Dickel, Soderberg, & van Oost, 2013). Makerspace sees artists and inventors coming together to create individual and collaborative original artefacts and can be anything from technology-rich items to knitting and craft materials.

The Makerspace approach sees makers situated in groups mentored to create a designated artefact. The artefact is presented to the makers who create and modify it to make it individualised and then take it home. This approach also has a definite and explicit focus upon the science, engineering and technology concepts involved, and the mentors are encouraged to use correct terminology as they question and support the school students (Blackley, Rahmawati, Fitriani, Sheffield, & Koul, 2018, p. 231). Table 2 below highlights some of the key differences identified in a targeted Makerspace learning activity.

Traditional Makerspace – recreational activity	**Makerspace approach – targeted learning activity**
Makers create their own communities	Makers are organised into pre-determined communities
Makers choose materials at their own discretion	Makers are provided with a base-level kit of materials
Makers envisage and produce individual, often unique, artefacts	Makers are shown a completed base-level & operational (as appropriate) artefact and are challenged to construct a similar artefact
Makers are not mentored	Makers are mentored (not instructed)
Makers might evaluate their artefact	Makers are scaffolded to evaluate their artefact
Makers might be cognisant of underlying science, technology, engineering, mathematics or other concepts	Makers are made aware of related underlying science, technology, engineering, mathematics or other concepts in line with curriculum documents

Table 1: Points of difference between traditional Makerspaces and the Makerspace approach

Education in India

There are more than 1.5 million schools with over 260 million students enrolled and at a tertiary level it has about 864 universities, 40026 colleges and 11669 institutes that cater for 3.57 million tertiary students (Mattyasovszky, 2017; United Nations Development Programme [UNDP], 2015). Education is controlled by each state as well as centrally through the government in Delhi and each state has its own Board of Education controlled by the Central Board of Secondary Education (CBSE), and responsible for conducting exams for Classes X and XII. Each state has a State Council of Educational Research and Training (SCERT) while, for the country, there is the National Council of Educational Research and Training (NCERT) (Sharma &

Sharma, 2015) There are a number of STEM initiatives currently being implemented in Indian classrooms through a range of institutions and industry focused projects (Kishore Vaigyanik Protsahan Yojana, 2017, December 26).

21st Century skills

"Skills have become the global currency of 21st century economies" (OECD, 2012, para. 5), and therefore it is important to consider not only student knowledge but also students' skills. The globalisation and internationalisation of the economy along with the rapid development of Information and Communication Technologies (ICT) are continuously transforming the way in which we live, work, and learn (Voogt & Roblin, 2012, p. 299). The skills and abilities required will shift to more social and emotional skills and more advanced cognitive abilities such as logical reasoning and creativity (Author, 2019). (United Nations Educational Scientific and Cultural Organisation [UNESCO], 2007) suggests that education policies and curricula must aim to incorporate a broad range of skills and competencies necessary for learners to successfully navigate the changing global landscape and that the curriculum needs to ensure that students develop attributes and skills necessary for a rapidly changing society and workplace. Various terminologies are currently used to capture, compartmentalise and name this shifting cluster of competences, including *21st century skills* or *21st century learning* (Griffin & Care, 2014; Kids, 2015), *key competencies* (OECD, 2005), *soft skills*, *new collar jobs* (Bughin et al., 2018) and *entrepreneurial skills* (Foundation for Young Australians [FYA], 2015). The term *21st century skills* is widely used, but many argue that the skills and capabilities referred to were important well before the 21st century, while also noting that with rapid change, century-long milestones are inappropriate (Voogt & Roblin, 2012, p. 301). For the purpose of this research the term transversal competencies from UNESCO is adopted and this includes the range of skills encompassed in the categories in Table 2.

UNESCO Transversal Competencies (2015)	21stCentury Competencies (2008)
Inter-personal skills	Critical Thinking and Problem Solving
Critical and innovative thinking	Creativity and Innovation
Inter-personal skills	Communication, Collaboration
Global Citizenship	

Table 2: Comparison of 21st Century Frameworks

Research Design

The methodology for this project was interpretivist qualitative research, based on an exploratory case study to examine pre-service teachers' engagement with and reflections on a Makerspace approach creating STEM artefacts – in this instance Wiggle bot, Catapult and Pipeline activities (Steminists, n.d.). The Wiggle bot artefact was a basic circuit, an upturned paper cup, with peg and pop stick (balance) with three pens as legs. Catapult required perseverance as PSTs received pop sticks, a plastic spoon and elastic band to create the model. PSTs were required to make the models from pictures and a video, without instructions, employing their theoretical knowledge and trial and error. The Pipeline was a team task where the group must build an enclosed pipeline over 2 metres long with 4 angles using only paper and tape which a small ball could travel down unaided. All the activities incorporated aspects of science, mathematics, engineering and technology. The research employed a paper-based survey of PSTs' engagement, including open-ended questions and observations to examine PSTs' engagement and reflections around their learning. The survey items and questions were developed and validated during previous international research (Sheffield & Blackley, 2016).

Context

The participant pre-service teachers (PSTs) were studying and living on campus at the Regional Institute of Education (RIE), Bhopal, a constituent unit of the National Council of Educational Research and Training (NCERT).

Pre-Service Teachers

Fifty-two female pre-service teachers studying in their 3rd and 5th semesters volunteered to participate in the workshops and were given STEMinist t-shirts and became part of the STEMinist community through the Facebook and website.

METHOD

The Indian STEMinist program was implemented as shown in Table 3 below, with the phases following the Reflective STEMinist Identity Formation Model (Figure 1) that was developed from the Reflective Identity Formation Model (Authors, 2016). The phases for each activity were split, with phases one and two completed at RIE on the first two days in Bhopal, and then phases three and four completed at the Demonstration Multipurpose School.

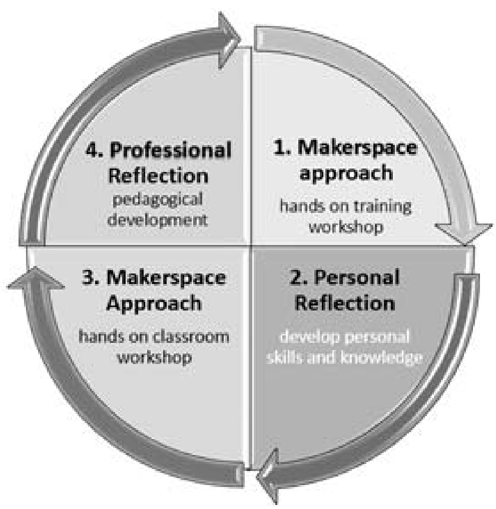

Figure 1. Reflective STEMinist Identity Formation Model

Data Collection

Anonymous surveys from 52 female pre-service teachers were collected as Part of Phase 2.

Data Analysis

The open-ended responses from the surveys were analysed using an aggregation of responses into themes;

including problem solving, creative and critical thinking, applied knowledge and collaboration. This was undertaken by two researchers independently and the results compared and moderated to ensure consistently. The group responses were analysed in the same way using the aggregation of responses into categories (Elliott & Timulak, 2005).

RESULTS

After completing the activity workshops before working with primary students the pre-service teachers were asked about their enjoyment.

All the PSTs said that enjoyed the project and some offered multiple perspectives (as a consequence N = 79 from a participant group of 52) Table 3 shows their responses to questions

What was the aspect that you most enjoyed?, What aspects did you find the most valuable?, What aspects did you find the most challenging?

Category	Responses (%)		
	Enjoyable	Valuable	Challenging
Collaborating	26	29	30
Applying science & maths	11	16	12
Problem Solving	14	23	19
Hands on Activities	20	7	12
Pedagogical skills	5	8	9
Engagement	13	2	9
Creativity	11	13	4
Other	0	2	4
Total	100	100	100

Table 3: PSTs' Responses

"I enjoyed, because it was teamwork, and also it was interesting, something which I haven't done before" was the response by one PST with 26% reporting that they enjoyed working with their peers. Another stated "It is the most creative learning project. It really teaches us to use the science, technology, engineering and mathematics in our daily life" with 20% of the PST listing a hands-on approach as a significant outcome. Twenty-nine percent of comments in this category related to collaboration and a further 23% to problem solving, with one PST summing up, "Problem solving and collaboration to solve a problem with cooperation and team is most valuable". PSTs were able to see the value of the activities in supporting their learning with a PST commenting, "Forcing us to think on our own. Motivating constructivism helps us to apply our knowledge and learn from ourselves".

Finally, PSTs documented the major challenges they experienced and 30% spoke specifically about issues with the Pipeline activity in including the number and size of the angles that were in the specifications and the use of the materials. They commented on the time constraints for all the activities and how having limited resources was also an issue.

Finally, in the PST were asked to consider the learning and make two comments about what they had learnt. These responses were aggregated and categorised into categories and these are presented in table 6. The majority of pre-service teachers, 66% articulated that they had developed a range of transversal competencies through the process of using the Makerspace Approach and creating artefacts. They reported that 32% developed collaborative and communication skills and were able to develop team skills. A smaller number 8% were focused on how the Makerspace workshops helped them to manage their time more effectively.

Category		Examples	%
General non specific		I would love any such amazing and full of life opportunity once and many more times.	6
Time Management		Keeping time limitation and unity	8
Pre-service teachers			
Self	General Knowledge	learn science technology and engineering	4
	General Skills	HOTS (High Order Thinking Skills)	9
	Communication	communicating our opinions to others in teams	12
	Collaboration	learning about communicating with others properly	20
	Problem solving	Thinking capability, problem solving skills	9
	Creativity	Creativity and collaboration	6
Teaching	General Teaching comments	Pedagogy- To teach learning by practical activity	3
	(School) Student learning focus	How to make the (school) students think (by asking questions)	13
	Total		100

Table 4: PST students to provide 2 new things that they have learnt related to your learning (N = 108 from a participant group of 52)

CONCLUSION

The Makerspace Approach in supporting pre-service teachers' engagement in STEM education

The pre-service teachers engaged enthusiastically in the STEM projects and made the Wigglebot, Catapult and Pipeline in the hands-on workshop, they reported that they found the workshops helpful and were very engaged.

"It is the most creative learning project. It really teaches us to use the science, technology, engineering and mathematics in our daily life" a pre-service teacher reported. They found the hands-on tasks engaging and were able to articulate the STEM knowledge they had learnt in these relatively simple artefacts. The pre-service teachers all reported enjoying the project, however, some also articulated issues that were challenging. When Collaboration was focused on, a total of 20% of PSTs articulated that it was the most engaging aspect of the projects and then 29% reported it to be the most valuable aspect to the activities but then 12% reported it as the most challenging aspect and one that they often struggled to manage.

Pre-service teachers identified a range of 21st century competencies as a consequence of their participation in the project

The PSTs learnt that, through these engaging activities, learning can take place and creativity can be developed. They also expressed the opinion that the activities were a wonderful method for developing 21st century competencies also known as transversal competencies such as cooperation, reasoning, time management, problem solving, team work, precision, accepting defeat and rejection, thankfulness, collaboration, respect for others, listening and accepting others viewpoints, accepting what is useful and neglecting what is unwanted, concentrating even when facing failures and learning from mistakes and rectification. They could clearly see how these skills were important to their learning and how the skills were an important part of the Makerspace alongside the content knowledge. PSTs also articulated that patience, guidance, perseverance and a desire to genuinely help the students learn are key aspects that need to be developed for them to become effective teachers.

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EXPLORING THE USE OF DEDUCTIVE LOGIC IN GEOMETRY AS A TOOL FOR COGNITIVE GROWTH

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This article presents some initial results from a study focused on promoting students' cognitive growth by building their deductive thinking skills in a college geometry course. The strategies used were ruler and geometric constructions and deductive proof.

INTRODUCTION

Historically, it is widely believed that learning mathematics fosters learners' cognitive development, and their problem-solving skills. Globally, mathematics is embedded within the school curriculum largely because mathematics is perceived as a subject that can help humans to learn to reason deductively, and apply such reasoning skills to everyday life. How to foster these reasoning skills? Most educators believe that deductive reasoning is a skill that must be acquired through careful and persistent nurturing. For students specializing in mathematics, by the college level, curricula include axiomatic reasoning and logic structures that are the foundations of mathematical proof, indicating that fostering cognitive growth by honing deductive skills is an important goal for mathematics education.

In this article, I present my work with a group of undergraduate students in a college geometry class. In this course, my goal was to intentionally foster students' deductive thinking skills by including tasks that would specifically target those skills. Thus, I intended to a) discuss the axiomatic development of geometric ideas so that students would appreciate the underlying structure, and use the structure to establish proof, b) include straightedge and compass constructions on a regular basis – students would do the constructions and prove that their constructions were correct, and c) encourage students to come up with their own proofs, with the intention of developing their deductive reasoning skills.

Specifically, the questions for my study were: (1) How can students be helped to appreciate and utilize the axiomatic development of Euclidean geometry? And (2) How can students' abilities in deductive logic be enhanced through construction and proving activities in geometry?

THEORETICAL FRAMEWORK

The work presented in this article is based on a framework supported by research in two broad areas of mathematics education: a) research on cognitive development in mathematics in general, and on the cognitive development of proof, in particular, and b) research on geometric thinking. Specifically, I was interested in helping students to reason deductively and to understand and appreciate the basic underlying axiomatic structure of geometric thinking. In doing so, I hoped that students would gain cognitive skills in mathematics and more specifically, in geometry.

One of the basic premises of my work is that the two seemingly disjoint approaches in mathematics – empirical intuition and deductive logic – are two pillars on which cognitive development in mathematics rests, and it is the interplay between these two aspects that engenders learning. This viewpoint has led to research on how best to support the dialectic between these two areas of distinct yet complementary individual experiences. Students and professional mathematicians, each in their own way, rely on the constant interaction of both these strategies in order to advance mathematically. Lakatos (1977), an early proponent of this viewpoint, asserted that mathematical development is a result of the constant interplay of empirical observation and formal mathematics, even coining the term "abduction" to describe the synthesis. Clarifying this perspective, Schoenfeld (1986) pointed out that empirical knowledge and deductive knowledge are mutually reinforcing, and each enhances the other in significant ways. In particular, I believe that geometry offers an ideal vehicle in which to transact and observe the cognitive growth stimulated by the constant dialectic of empirical reasoning and deductive logic. There are several reasons for my belief.

First, in general, geometrical entities are easier to visualize and manipulate for students than other mathematical objects, and the access to visual representations facilitates the development of reasoning skills based on properties and attributes of geometrical concepts. Secondly, Euclid's approach to geometry, outlined in the *Elements*, was constructive. Many of Euclid's theorems are exercises in construction, based on deductive logic. Further, the constructions are accessible for students, most of whom are introduced to the basic constructions in school geometry. As students develop proofs for these results, they experience the element of problem solving. Thirdly, curricula in geometry have been quicker to evolve towards facilitating the interplay between the areas of empirical experience and deductive reasoning. Wirszup (1976) declared that (deductive) proof cannot be meaningful until the entities manipulated in the proof are meaningful. Thus, early on, educators broadly recognized that purely axiomatic initiation into the study of geometry is bound to be largely unsuccessful, and found ways to incorporate hands on experience with geometrical objects at the earlier stages of schooling via tangible objects, visual representations, and real-life experience. I believed that straightedge and compass constructions offer an excellent opportunity to combine these experiences and engage students.

The ground breaking work by Dina van Hiele-Geldof (1957) and Pierre van Hiele (1957) provided further support for a pedagogical approach to geometry that relies on enhancing students' experiences with geometrical entities, and reflecting on properties of the entities in an interactive manner. The van Hieles provided empirically based description of five stages of geometric learning that delineate the stages or levels that learners go through when developing ideas related to geometry. Modified from Lee, (2015), the levels may be articulated as follows:

- *Level 1*: Visualization: Students can recognize and classify shapes based on visual characteristics of the shape. They are unable to articulate properties of shapes.

- *Level 2*: Analysis: Students can identify some properties of shapes, and use appropriate vocabularies. They cannot use the properties for logical deduction.
- *Level 3*: Informal deduction: Students know the relationships among properties of geometric objects and are able to do informal logical reasoning. They cannot create formal proof.
- *Level 4*: Deduction: Students know the deductive systems of properties and can create formal proof.
- *Level 5*: Rigor: Students can do analysis of deductive systems and compare different axiom systems.

The van Hiele levels are hierarchical but non-discrete, and each subsequent level draws upon understanding built at the previous level. Students must gain sufficient experiences at one level before proceeding to the next, and students will function at different levels simultaneously, depending on the concept. In laying out these principles, the van Hiele model of geometric thinking is useful in two significant ways: 1) The model is useful in understanding where students are situated in terms of cognitive development, and has been used by researchers for this purpose, for example, by Mayberry (1983), 2) the model may be used to develop a pedagogical approach that helps students to transition from an earlier to a later stage, thus moving towards cognitive growth. In their study describing the van Hiele levels of geometric reasoning among students, Burger and Shaughnessy (1986) verify that the levels were useful in describing students' thinking processes on geometric tasks, and that the levels could be characterized operationally by student behavior. Their work suggests that the levels are useful in making pedagogical decisions about students' development in geometry, and designing tasks that aim to raising students to the next level.

The findings of the above research propelled me to use the van Hiele model to help me ascertain where my students were in terms of geometric thinking, and designing experiences that would help them to advance their geometric thinking to the next level. In their report, Tall et al (2012) traced the long-term cognitive development of mathematical proof. Their framework is initiated from perception and action, and evolves through proof by embodied actions and classifications, geometric proof and operational proof in arithmetic and algebra, to the formal set-theoretic definition and formal deduction. The research provided me with some pointers on how to design tasks that specifically foster cognitive growth.

DETAILS OF THE STUDY

For my study, students were drawn from a college geometry class that I taught in the mathematics department of a state university in central New York. Many of the students were preservice secondary school teachers for whom the course was required; almost all of these students had mathematics as a second major. The other students in the class were mathematics majors who were taking the course as an elective. I encouraged the students to work in pairs or in small groups while working on construction problems or proofs. I collected data by observing student work, by writing detailed notes after class, and by taking pictures of student work.

STRUCTURE OF THE COURSE

Most students in the class had taken a geometry course at the high school level. Based on their initial work in class, and on a homework assignment, I found that a majority of them were (mostly) at level 2 of the van Hiele model. They had understanding of properties and attributes of shapes, and tried to reason based on the properties. However, they reverted to the visual aspects of the shape when they encountered an obstruction in the problem-solving process, indicating a reversal to level 1 of the van Hiele model. A few of the students – about 3 or 4 – could be considered to be more at level 2. They tried to enunciate abstract definitions. Sometimes, they offered logical implications, based on the definitions. 1 out of the 22 students functioned mostly at level 3 of the van Hiele model. He was able to use deductive logic to create informal proof but often needed help with formal proof. He tried to incorporate new theorems into an existing network of geometric knowledge.

My objective in the course was to find ways to help students transition to level 3 of the model. This is the level where students think deductively, and I believe that if students became proficient at this level, then they would be sufficiently prepared for the courses that were to follow. To promote students' deductive skills, I chose largely two strategies (1) proof-based activities involving increasingly complex results that would include deductive logic, and (2) ruler-and-compass based constructions, that would include developing the construction, and justifying it. Both these activities would engage students in using the basic axioms and results of geometry, and would evolve as they added more results to their repertoire. Thus, I designed activities on an everyday basis that were geared towards these two strategies.

In the first few weeks of the semester, we laid out the basic foundations of Euclidean geometry contained in the first book of the *Elements* – beginning with the 23 definitions, the five common notions and five postulates, and the early propositions (http://aleph0.clarku.edu/~djoyce/java/elements/bookI/bookI.html#cns). Among Euclid's first 12 propositions, seven involve construction. The students did these constructions, and for each one, students would prove the constructions were correct by using previous propositions and the common notions and postulates. A crucial component of the class was the small groups in which students worked – they pushed each other to justify their reasoning by asking questions such as "which result are you using (for a given step)?"

In addition, the textbook we were using (Libeskind, 2008) also facilitated the process. As in Euclid's *Elements*, the book formulated constructions as theorems requiring proof. For example, theorem 1.12 in chapter 1 characterizes an angle bisector as follows: A point is on the angle bisector of an angle if and only if it is equidistant from the sides of the angle. This theorem came up early in the course, and followed a section in which students defined and studied the properties of kites. Once students understood such a statement, they began to see that the statement reflected their construction, and was a tool to help them analyze their steps. Thus, students knew (from theorem 1.12) that in order to construct an angle bisector, they needed to construct the set of points that was equidistant from both arms of the angle. Having studied the properties of kites, some students knew that the diagonals of a kite are angle bisectors for the angles that they connect. They used this idea to construct a kite using (parts of) the two arms of the given angle (see figure 1).

Here, students used the result that the diagonal (BD) of a kite (DEBF) bisects the angles at the vertices that it connects. Thus, students drew a circle with center B, and radius BE. This construction created the sides

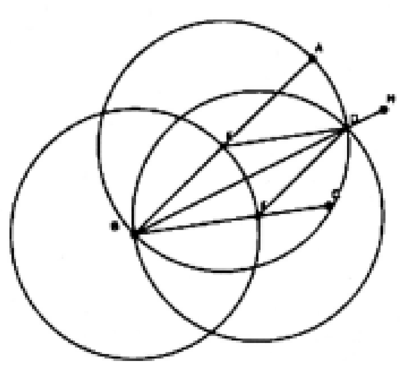

Figure 1

BD and BF of a kite. Students then completed the kite by drawing circles centered at D and F respectively with the same radius DE = FE (actually, students more often drew a rhombus). Thus, EB is the angle bisector of angle ABC.

Further, the exercises in the book required students to construct various geometric entities, and then prove that the construction was correct. The first few weeks helped to set the tone of the class, and to master the basic constructions.

Another important strategy that the book suggested for solving construction problems was outlined in three steps: Step 1) Assume that the construction is done 2) Analyze the construction and the shapes in it for various attributes and properties. Step 3) Use the properties and attributes to work backwards and carry out the construction. I strongly urged the students to use this strategy. An early attempt by students to utilize this strategy is described below.

Episode 1

Question from the exercise in Libeskind (2008, p. 38): A circle such that each side of a triangle is a tangent to it is called an inscribed circle. Assume that a tangent to a circle is perpendicular to the radius at the point of contact. Explain how you will find the inscribed circle, and then construct it. (Question restated in Figure 2)

Given: Δ MNO.
To construct Inscribed circle in Δ MNO

Figure 2

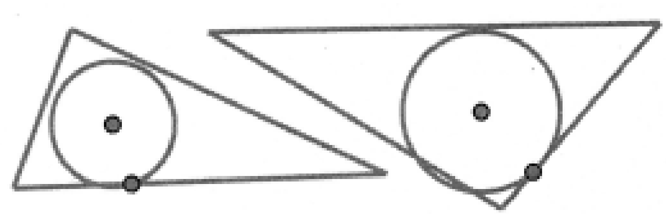

Figure 3

Students attempted this problem in pairs or in groups of three. Some students immediately drew a triangle and then tried to construct a circle inside it by guessing a center and a radius. Figure 3 shows the typical attempts. Clearly, this strategy did not work. I reminded them of the 3-step strategy outlined above. For step 1 of the process, students needed to assume that the shape had been constructed, and draw what the resulting construction would look like.

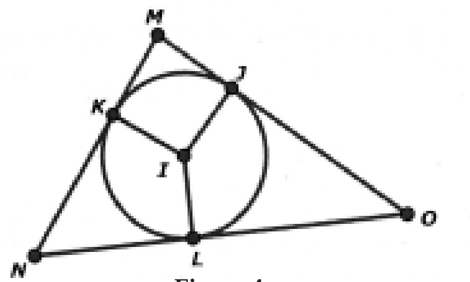

Figure 4

Soon, students realized that it was easier to draw the circle before they drew the triangle. One pair of students, Alexa and Joey, (pseudonyms), who were working together, drew the diagram in Figure 4 as a rough sketch of what the picture would look like if it were actually constructed. Thus, they first drew the circle (I), then chose three points (J, K, and L), then drew the three tangent lines. Then they proceeded to analyze the picture.

Their conversation was as follows:

Alexa: So, how do you think these (pointing to IJ, IK, IL) are related? I mean, I know they are radii but what else?

Joey: Yeah, there has to be something else, right? (They looked to me, and I stayed quiet)

Joey: Looks to me like these are perpendicular bisectors or something …

Alexa: You mean of the sides? Hmmm … yeah, but like, NL looks much shorter than OL. (After some thinking) So, did we draw this wrong? (Long pause)

Joey: But the sides have to be tangents, and they are, aren't they? (This last question was addressed to me, and I stayed quiet)

Joey: (after a pause) Well, the tangents have to touch at one point.

Alexa: (thinking) But that's not how we defined it. Look (turns back a few pages to show the highlighted definition in her notes). It says: the tangent is a line that is perpendicular to the radius at the point of contact. So, we have to assume that these lines are perpendicular to the radius.

After a while when I came back to them, they had marked the right angles IKN, ILO, and IJO.

Discussion: Analyzing this episode, I believed that Joey's purely visual reasoning indicated level 2 thinking – in the picture, he thought that the radii looked like bisectors (though even this was contradicted by Alexa). Similarly, their initial conception of a tangent being a line that "touches" a circle ("touching" being an undefined concept) was indicative of level 2 thinking. However, Alexa's reference to the definition as a step towards their construction indicated a readiness to move to deductive reasoning. I believe that reasoning on the basis of the definition was an important step in advancing students' geometric thinking, and showed a move towards level 3.

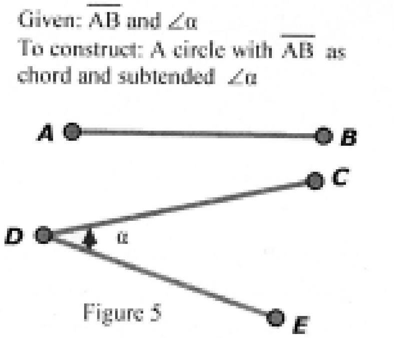

Figure 5

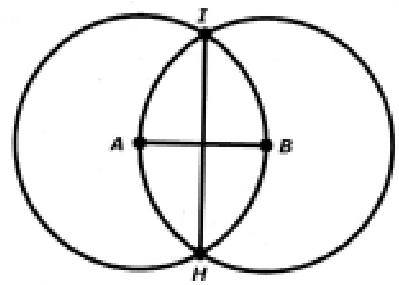

Figure 6

Episode 2: A few weeks later, students worked on the following construction problem:
Given an angle*a*, and a line segment *AB*, construct a circle that has *AB* as a chord with *a* being the angle subtended by *AB*. I asked students to draw their own angle *a,* and a chord *AB*.

When students worked on this problem (restated in Figure 5), they quickly pointed out that based on postulate 3, they needed the center and the radius of the circle in order to construct it. After some time, I joined a pair of students, Stephanie and Dana (pseudonyms), to observe their work.

Stephanie: Should we begin with the angle, or the chord?

Dana: So, if we could draw the angle, like this (she drew the vertex of *a* at the top of the page, and the arms extended downwards), then I can try to fit the chord *AB* (indicating line segments between the arms)? Right?

Stephanie: So you mean by *measuring*? (Her emphasis) Ha, ha! Not allowed! (They both looked at me, and laughed) Against the rules, right?

I: You've got that right! (We laughed together).

Dana: (thinking) OK. One thing I know. The center lies on the perpendicular bisector of a chord. We've proved and used that before – I remember that.

Stephanie: I agree. So, let's draw that. (When I came back a few minutes later, they had constructed a copy of AB, and constructed its perpendicular bisector IH – see figure 6). Now, how do we find the centre (of the circle) on this line (pointing on IH).

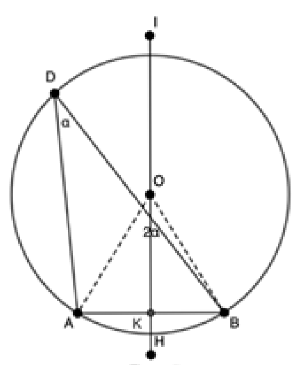

Figure 7

At this stage, they tried several unproductive strategies. Then, they overheard another student, Ben (pseudonym) talking about assuming that the figure had already been constructed. So, Stephanie and Dana decided to try that strategy, and drew the picture as in figure 7 (without the dotted lines). Then, they flipped the pages of their notebooks, considering various other results about circles that we had proven in class. Finally, they found the theorem that stated that for a given subtended angle on the circumference of the circle, the central angle subtended by the same chord is twice the subtended angle on the circumference (that we had done in a previous class).

Stephanie: (pointing to the diagram for the theorem) Doesn't this look like the picture we are trying to construct?
Dana: Yeah, that's what I was thinking. We can do this (She drew the dotted segments OA, OB)
Stephanie: Looks like we have two congruent triangles here.
Dana: Where?
Stephanie: (labelling K) See, right here. Triangle AKO, and triangle BKO. Because radii (OA, OB) are equal, AK = BK, and angles at K are right angles (pointing to each object).
Dana: So, hypotenuse-leg (writing HL). OK, I see. So now angles at O (angles AOK, BOK) are equal to a. Hm, that is nice, isn't it? Because if we now make AD parallel to OH …
Stephanie (interrupting) But AD is not parallel to OK.
Dana: Yeah, but we can choose it that way because all these angles subtended on AB are equal, so we can pick one whose arm is parallel to OK.

The students completed their construction using this idea.

Discussion: This was a challenging construction problem for students; they needed to use two theorems (that were relatively new to them) in conjunction. In order to combine these results they had to use deductive reasoning. The students would need to recognize and use the relationships between (a) the centre of a circle, and the perpendicular bisector of a chord and (b) between the angles subtended by the same chord at the centre and on the circumference. Students knew the statements of the related theorems but utilizing the statements to construct the centre of the circle forced them to apply the theorems in a new context Dana and Stephanie were able to use the relationship in (a) quite smoothly indicating level 3 thinking; however, the relationship in (b) above was a little more subtle. The crucial steps in recognizing and using that relationship came when they overheard Ben (thus being prompted by an outside source) and seeing the picture for the theorem. So, they were able to reason through the second part of the problem – a progression towards level 3 thinking; they even did some formal proving activities unprompted (recognizing congruent triangles and identifying the criterion) which is classified as level 4 thinking in the literature (Lee, 2015; Fuys, Geddes, and Tischler (1988)).

CONCLUSION

At the beginning of the class, students presented their arguments citing properties of geometrical objects that they were very familiar with such as triangles, rectangles or parallelograms. We then discussed the initial part of the *Elements* in some detail, including some of the definitions, and why definitions were useful; in particular we discussed how the foundations of geometry as laid out by Euclid, were instrumental in moving learners forward in thinking deductively.

As evident from the two episodes described in this paper, there were marked differences in the ways that students built their constructions at the beginning and then towards the end of the semester. The students were definitely connecting their ideas more by using propositions and results that we had proved in class, indicating that they were ready to progress to a higher level of the van Hiele model. In the context of the model itself, it was evident that even for the same problem, (the same) students could function at more than one level simultaneously. As their instructor, this was exhilarating; as a researcher, this made the work of classifying the students by levels a little more thought provoking. The inter-student interaction was very helpful in maintaining a productive atmosphere in the class where students discussed ideas and defended their arguments with each other. Certainly, it gave me hope to extend my work and my efforts towards more work in this area.

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DEFINITION OF AN ARTIFICIAL INTELLIGENCE ENGINE FOR MATHEMATICS EDUCATION

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The National Education Policy Draft (2019) proposes that students across over a million schools have to achieve an adequate level of numeracy. While it may be a challenge to find quality teachers at such a large scale, certain facets of their wisdom and experience could be encapsulated in an Artificial Intelligence (AI) engine. The application of AI to education has been explored by various researchers. Here, we specifically investigate the considerations to develop an AI engine for school-level numeracy. Further, we incorporate these considerations into a probabilistic framework and propose the definition of such an AI engine.

Keywords: *Artificial Intelligence, Mathematics Education, Probabilistic Framework*

INTRODUCTION

Over the years, researchers have noticed that Artificial Intelligence (AI) engines can be trained to yield predictions that exceed human accuracy. This is achieved by applying a high quantum of computational effort to massive, and possibly ill-formed or poorly-defined data sets. Given this attractive feature, AI has been used for a variety of industrial applications (Nadimpalli, 2017). AI has been applied in education as well (Chassignol et. al., 2018), the aim being to have a program mimic the efforts of an expert teacher.

To build an engine capable of mimicking human effort, it is first necessary to understand how the learning process works, and how it is influenced by the teacher. At a middle-school level, an expert teacher may juggle limited resources to present different perspectives on a topic (Matic, 2019). At the secondary-school level, the teacher may need to respond to different understanding process used across students (Radmehr & Drake, 2019). In addition to methods of teaching and understanding, there are other factors that affect learning outcome. As pointed out in (Shah & Chandrashekaran, 2015), learning the sciences requires practice on the part of the student, and it could be beneficial to use the classroom as a practice session, rather than for just lecturing. Generations of teachers have educated students, and there is quite a challenge ahead to incorporate all of this perspective into an automated engine.

The focus of our effort has been to define a scalable education system for mathematics and numeracy that will help achieve the goals proposed by the Government of India's National Educational Policy (Kasturirangan 2019). While it is not possible to have an expert teacher in every school in the country, it may be possible to scale a software-based solution. To succeed in this endeavour, it is imperative to sensitivize ourselves to the issues faced in urban, rural and tribal areas. A common obstacle encountered in both urban (Matthews, 2018) and tribal (Panda, 2006) areas is closing the loop with some assurance of expected learning outcome for the given funds. Moreover, social inequities also play a role (Harper, 2019), and should be handled with sensitivity. Fortunately, a software-based AI engine is agnostic to human aspects like socio-economic level, caste, or race, and could also go a long way in encapsulating the insights of experienced educators.

What we have accomplished so far is as follows. We have developed an Android-based application for practice of all aspects of mathematics from grade 1 to 10 of the CBSE syllabus. Well-trained teachers use this application to create customized sessions for each student with a combination of questions from various topics at selected levels of difficulty. Over 35,000 students have used this application, and a vast quantity of data has been generated. The next step that we would like to take is to automate the process of selecting customized sessions by quantifying the data collected, building a statistical model, and developing the required AI engine. This is the area of research of the current paper.

The current paper focuses on quantifying three aspects of the learning process, and then moves on to propose a design for an AI system. Firstly, we need a statististical model of difficulty level of each topic. This is addressed in section 2. Second, we need to characterize whether a student has exhibited proficiency in a topic from short-term memory or is the internalization of the topic deeper than that. Section 3 focuses on this aspect. Third, given that the various topics of mathematics have intricate interdependencies, to what extent would exposure to a related topic assist in mastering the current topic. This is addressed in section 4. Finally, in section 5, we use these empirical probabilities to construct a statistical framework to optimize the probability that a student will make progress. Various real-world constraints are included in the model, including the fact that mathematical topics often have prerequisites that would need to be first be mastered, and the fact that a class period is usually of limited duration, and this time would need to be optimally used. We now get into the details.

STATISTICAL ESTIMATION OF DIFFICULTY OF A TOPIC

To estimate the level of difficulty of a topic, we not only need to measure the average marks in this topic, but also need to consider other factors including (i) quantifying the initial effort required to acquire a basic level of competence, (ii) the statistical variation of competence with stringency of requirement, and (iii) the variations in duration needed to attempt and succeed in various topics. Figure 1 sheds light on the first two considerations. The third consideration is addressed later in this section.

Initial effort to acquire competence

The y-intercept of the graphs of Figure 1 indicate the number of attempts required to attain an intial level of competence in various topics. By initial level, we mean that the student should correctly answer at least 3 consecutive questions of this topic. The x-axis of this graph denotes the required number “n” of consecutive correct responses required.

Certain topics (like “Quadrilaterals”) require a high level of initial effort to master the concept. In this topic, on an average, students have attempted 7.1 questions before they could correctly respond to 3 consecutive questions. On the other hand, in a topic like “Lines and Angles”, students, on an average, needed to attempt only 4.2 questions before they exhibited the same level of competence.

Implication of Statistical Variation of Competence with Stringency

It may be necessary to vary the stringency of the requirement “n” depending upon how often a topic is needed as a prerequisite. As an example, a topic like “Decimals” (taught initially in 5th grade) serves as a prerequisite for a variety of topics in future years. However, a topic like “Bodmas” is a prerequisite much less often. For a topic like “Decimals”, the stringency requirement (i.e. the parameter “n” on the x-axis of Figure 1) may need to be increased.

Two features of the data stand out in Figure 1. The first is that on an average, some topics need more attempts to attain a given level of proficiency. For example, the graph for “Quadrilaterals” is higher than the graph for “Triangles”. In the ensemble of students tested, questions in the topic “Quadrilaterals” were more challenging than those in “Triangles”.

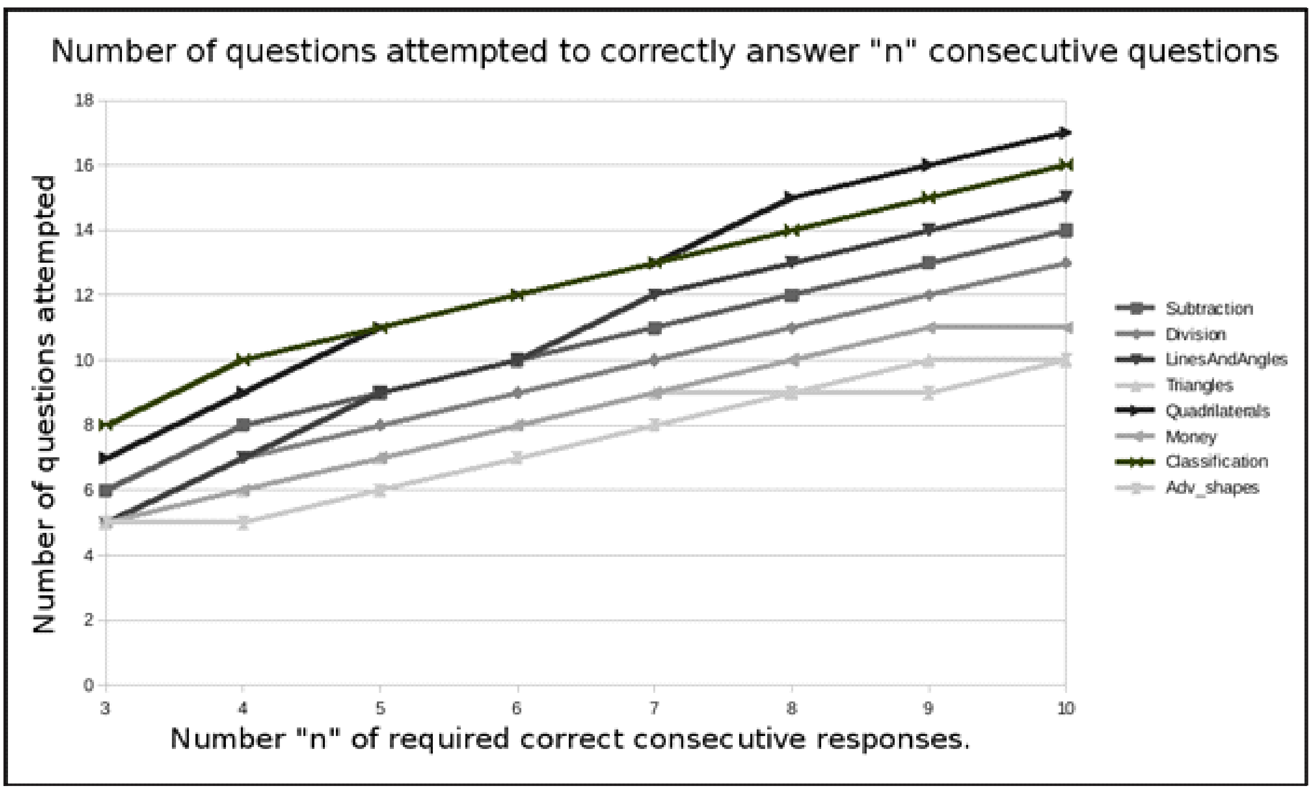

Figure 1: The number of questions required to internalize a topic increases with the parameter on the x-axis, and the variation is different for different topics

The second feature that stands out in the graph of Figure 1 is the shape of each curve, whether the second derivative is positive, zero, or negative. In some topics, the curve tends to have a positive second derivative, meaning it is accelerating upwards. The examples are “Quadrilaterals” and “Lines and Angles”. In these topics, after the student has gained some proficiency, there is a higher level of challenge to continue to maintain that proficiency. This often happens in questions which require a high level of focus.

In some topics such as "Division" and "Subtraction", the second derivative is zero. Here, the level of focus required is just proportional to the number of questions given. While the duration required to solve a division question may go down with practice, the number of questions to be solved to meet a particular level of proficiency simply increases linearly with the required number "n" of consecutive correct responses.

Finally, some topics such as "Money" and "Advanced Shapes" exhibit a negative second derivative. Here, students may take a few attempts to determine how to solve the question. Once a level of proficiency has been attained, it is relatively easy to maintain that level.

Average Percentage and Duration

Given an ensemble of students, there is a variation of average percentage attained and mean duration required across topics. A particularly useful metric is the mean duration, because this is an indicator of how much effort the student is putting into this topic. These values are tabulated in Table 1.

In Table 1, we can see that topics can be grouped into three clusters: (i) Highly procedural topics like "Subtraction" and "Division", (ii) topics that initially require thinking but for which the student eventually derives a procedure, like "Lines and Angles", "Triangles", "Quadrilaterals" and "Money", and finally (iii) topics that are essentially logical reasoning (like "Word Classification" or "Advanced Shapes") for which there is no standard procedure.

Topic	Average Percentage	Mean Duration (Minutes)
Subtraction	95.13	3.10
Division	86.19	2.64
Lines and Angles	84.65	1.17
Triangles	82.84	1.07
Quadrilaterals	80.34	0.73
Money	79.69	1.08
Classification	63.79	0.49
Advanced Shapes	86.32	0.21

Table 1: The average percentage attained and mean duration required while solving questions in various topics

In highly procedural topics like "Subtraction" and "Division", students do take a long time to solve questions, but are not particularly flummoxed by the type of question or the juxtaposing of this question with questions from other topics (discussed in the next section and elucidated in Figure 2).

In newly introduced mathematical topics like "Lines and Angles", the student usually requires a while to determine how such questions are solved, and eventually develops his/her own procedure to solve these questions.

When we have topics focusing on logical reasoning, like “Word Classification” or “Shapes”, the student is able to quickly answer the question, but the frequency of getting the answer correct may or may not be high. This does not necessarily imply that the student is guessing (although that continues to be a possibility), but could mean that determining the classification or matching shape is a quick process without the labor of a standardized procedure.

All of these metrics to measure the difficulty of a topic need to be modulated by an orthogonal factor, which is whether the student is attaining competence using short-term memory, or is truly internalizing a topic for recollection at a later period in time.

Short-term versus Medium-term Proficiency

There are various time-frames in which to measure the idea of competence, roughly speaking, the short-term, medium-term, and long term periods (Norris, 2017). A short-term approach would be having a student attempt only one particular type of question until s/he starts getting it correct over a number of consecutive attempts (for example, “Fractions”). This offers both an intellectual and psychological benefit to the student. Once this level of proficiency has been attained, the next stage (i.e. medium-term horizon) would be to solve a question in a given topic interspersed with questions from other topics. In the longer-term, the student would be expected to answer questions from this topic many months after first attempting it, for example, in a final exam. In this research, we focus on the short and medium term.

In Figure 2, we show the empirical probability of being posed questions from mixed topics while correctly solving questions in various topics. The larger this number, the more ability students have, on an average, to correctly solve questions in this topic while switching context. Based on whether a topic is highly procedure-based or application-based, the ability to switch topics tends to vary. The foundation for the metrics and selection process (choosing topics, number of questions, measuring consistency) is discussed in (Swaminathan 2015).

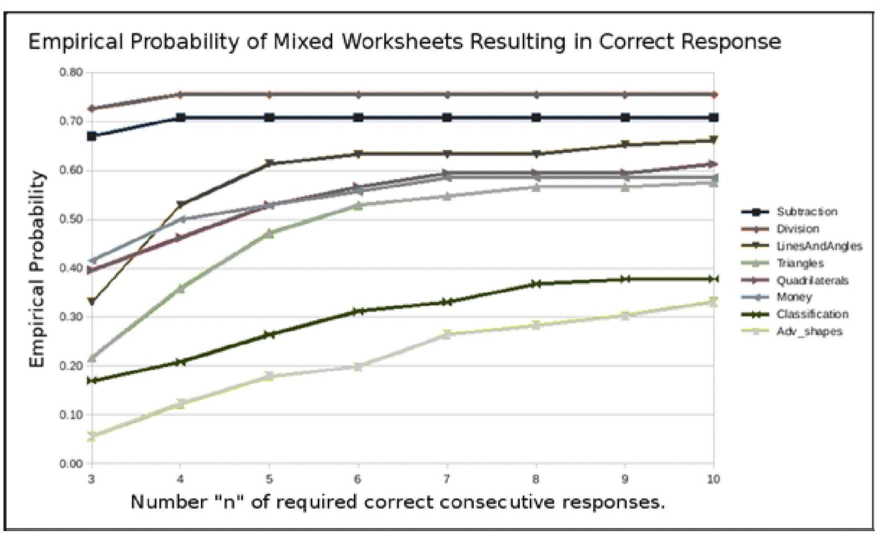

Figure 2: The empirical probability of allowing mixed topics while acquiring proficiency in any topic tends to increase as the parameter on the x-axis increases.

In highly procedural topics such as “Subtraction” and “Division” it is easy to gain proficiency and continue to maintain this proficiency despite the context being switched between different topics. Even with as high a context switch probability as 0.75 (i.e. 75% chance of context being switched), students, on an average, are able to attain and maintain proficiency.

Then, we have a topic like “Lines and Angles”, which starts off requiring a high level of single-topic focus (only 33% of the time does a switch in topic result in a correct response), but moving up to the possibility of a high level of multi-topic focus (can switch topics 67% of the time). Our teachers have observed that in such topics, the student needs single-topic focus to understand a new concept, and once this concept has been internalized, it is easier to handle this topic in conjunction with other topics.

Finally, we have topics in the realm of logical reasoning rather than conventional syllabus mathematics. Examples include “Advanced Shapes” (finding the matching shape) and “Classification” (word classification). In such topics, the data indicates that the student finds it difficult to retain proficiency in this topic while switching between topics.

The variation has dependence on whether the topic is highly procedural or more application-based. It is of interest to compare the data of Figure 2 to that in Table 1 since the clusters observed in both data are similar. In highly procedural topics such as “Subtraction” and “Division”, Figure 2 indicates that the student is able to handle the topic interspersed with other topics, and Table 1 indicates that the student requires a reasonably long time to perform this procedural task. In newly-introduced mathematical topics like “Lines and Angles”, “Triangles”, “Quadrilaterals” and “Money”, Figure 2 shows that the student initially needs to focus exclusively on this topic, but as competence is attained, is able to switch between other topics. Hand-in hand, Table 1 indicates that the student requires just about 1 minute to solve the question. The third cluster comprises topics focusing on logical reasoning, like “Word Classification” and “Advanced Shapes”. Figure 2 indicates that the student needs to focus exclusively on such topics to gain proficiency, and Table 1 indicates that the duration to solve these questions is quite low. There is no elaborate procedure to classify or select a matching shape, and questions can be answered quickly. However, it appears to be challenging to attempt such questions after answering questions of a completely different nature.

INTER-TOPIC DEPENDENCIES

Mathematics is a highly interconnected science. The solution to a problem may be inspired by working on an area of mathematics that bears but a subtle relation to the original problem. This observation inclines us to ask the question, “In order to correctly solve a problem in the current topic, is there another topic that could be presented prior to this that would perhaps stimulate a style of thinking conducive to solving this particular problem?”

To get a question correct in Division		To get a question correct in Lines And Angles		To get a question correct in Quadrilaterals	
Topic Given Earlier	Frequency	Topic Given Earlier	Frequency	Topic Given Earlier	Frequency
Division	1203	Lines & Angles	1343	Quadrilaterals	790
Multiplication	331	Area Volume	290	Area Volume	102
Place Value	269	Percentage	42	Circles	59
Subtraction	95	Decimals	31	Percentage	20
Fractions	62	Circles	19	Decimals	13
Mixed WP	55	Triangles	15	Lines & Angles	12
Factors Multiples	33	Fractions	11	Fractions	9
Measurements	21	Factor Multiples	10	Triangles	9
Percentage	16	Olymp Time	7	Directions	8
Area Volume	16	Word Classification	6	Mixed WP	7

Table 2: Frequency of topics attempted prior to getting a problem correct in the current topic

One can shed light on this matter by examining, for any given topic, the frequency with which various topics were attempted prior to correctly answering a question in this current topic. As can be seen in Table 2, prior to getting a question in “Quadrilaterals” correct, students had attempted questions in the same topic (i.e. “Quadrilaterals”) 790 times, and had attempted “Area Volume” 102 times. To be clear, the students have correctly solved questions in “Quadrilaterals” 102 times after merely attempting a question in “Area Volume”, and not necessarily getting the question in “Area Volume” correct.

In all cases, the best prior topic appears to be the topic itself, but this observation may have to be taken with a nuanced viewpoint. Often, the teacher makes a student continue to work on a particular topic until s/he attains a reasonable level of competence. Even under such a possibly suboptimal circumstance, it is noteworthy that working on other topics may have a significant desirable impact on gaining proficiency in the current topic.

Given that an Artificial Intelligence engine can handle mammoth quantities of data and run algorithms that are based on probabilities, the solution that suggests itself is to use each topic as a prior with a frequency proportional to its empirical probability, and continuously update the table of empirical probabilities.

DEFINITION OF AN ARTIFICIAL INTELLIGENCE ENGINE FOR MATHEMATICS EDUCATION

In this section, we define an Artificial Intelligence engine for mathematics education. The main objective of this section is to utilize the findings of the previous sections to create questions for the student that will be at the appropriate level and maximize the probability of the student making progress, given the time constraint of the class period.

We start by defining a few terms, then list out the empirically obtained quantities required. Then we build up the criterion that will be optimized to decide what question should be given to the student. Finally, we define the engine that uses a Bayesian model to generate a customized sequence of questions that will be optimal for the student.

Let us establish the terminology of "Level", "Prerequisite Factor" and "Accessable Level".

- Level: For each topic in mathematics (like "Addition", "Fractions", etc.), there would be several "Levels". Roughly speaking, a Level is a section of a chapter of the textbook. So if the level is 503, that might refer to the 3rd section of a 5th grade textbook. We define C_i to be the event that the student acquires consistency in the i-th level, and t_i to be the expected value of duration to correctly answer questions at this level.

- Prerequisite Factor: Each level in mathematics could serve as a prerequisite to a variety of other levels. For example, a level like one-digit addition would probably serve as a prerequisite to most of mathematics in the current and future years. The "Prerequisite Factor" is a measure of how many future levels in various topics depend on this particular level. We define F_i to be the prerequisite factor for the i-th level. Thus, F_i for one-digit addition would be a high number.

- Accessable Level: A level for which all prerequisites have been successfully completed is said to be an "Accessable Level". Let ***A*** be the set of all currently accessible levels. This will be set on a per-student basis. Now, for each level, the quantities required will be: (i) the required number "n" of questions to proficiency (the x-axis of Figures 1 and 2), which is decided by a panel of experts, (ii) the average number of questions to gain proficiency, which is obtained empirically, (iii) the average duration needed (obtained empirically), and (iv) the probability of having a mixed session (obtained empirically from Figure 2).

Using these quantities, we would like to define a criterion "J" to be optimized. Given a maximum time "T" and the constraint "M" that we want mixed topics if possible, we define

$$J=\sum_i F_i P\left(\frac{C_i}{M}\right) \text{such that } \sum_i t_i \leq T \text{ and } i \in A$$

as the criterion to be optimized. Essentially, we would like to maximize the expected value of prerequisite factors of competence, given that we are doing mixed topics and constrained to accessible levels, within the stipulated duration of a class period.

The value of $P(M/C_i)$ can be read from Figure 2, and emiprical values of P(M) and $P(C_i)$ can be extracted from data. Using Bayes' Theorem, we get

$$P(C_i/M) = P(M/C_i)\ P(C_i)\ /\ P(M)$$

which can be used in the criterion J to be optimized. Further, the specific set of mixed topics can be selected probabilistically, by creating a probability density from the data of Table 2.

The levels selected will be determined by a greedy search algorithm, maximizing the values of F_i with $\notin \boldsymbol{A}$. Also, ***A*** is updated each time the required proficiency of any level is attained.

The above algorithm maximizes the expected value of prerequisite factors of competence using empirical probabilities from a global ensemble. Future work includes modifying these probabilities on a per-individual basis, and a multi-resolution approach for prerequisites.

CONCLUSION

It is a signifcant challenge to enable all of the schools of India (over a million in number) to have the benefit of an expert teacher for mathematics. However, some facets of such expertise could be codified into an Artifical Intelligence engine, and scaled across schools. The National Education Policy Draft (Kasturirangan, 2019) specifically mentions technology as an enabler of quality education at scale. The current paper has outlined the issues related to and the process of developing an AI engine specifically for mathematics education.

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LEARNING CONTROL SYSTEM DESIGN USING NANO DRONE IN A PBL FOCUSED ONLINE ROBOTICS COMPETITION

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Teaching advanced conceptual knowledge and practical skills in a hands-on-manner to a large number of students is a challenge. The e-Yantra project hosted in IIT-Bombay, through it's e-Yantra Robotics Competition (eYRC) for college students, teaches these skills scalably. Participation is free and hardware is shipped to participants who are mentored constantly throughout the competition. The 7th edition of the competition, eYRC-2018, had a theme (a gamified problem statement), called "Hungry Bird," that taught Marker-Based Localization, Path planning using OMPL, and Waypoint Navigation using PID on a nano-drone using open source platforms such as ROS and V-REP. This paper outlines how we optimally designed and deployed these concepts as a series of tasks which eventually helped us to quantify the learning outcomes among students. 832 students were assigned this theme, and to achieve scale most of the tasks were automatically evaluated. Finally we illustrated how we have achieved the effectiveness of the theme with task results and participant's feedback. This study and its outcomes are beneficial for academicians seeking to teach advanced engineering skills at a large scale.

INTRODUCTION

e-Yantra, a project at IIT Bombay funded by the Ministry of Human Resource Development (MHRD), exists to develop and deploy transformative digital pedagogies to train both college faculty and students the concepts of robotics and embedded systems. One way e-Yantra implements this for students is through the e-Yantra Robotics Competition (eYRC) (Krithivasan et al., 2014a) that has been growing exponentially since it's launch in 2013 having had 28000 registrations (as teams of four students) in the 2018 (eYRC-2018) edition. The eYRC competition has effectively shown that students learn while competing and compete while learning (Krithivasan et al., 2014b) and delivers hands-on learning to a large number of students across the country at the undergraduate level. The training follows a project-based learning approach that teaches participants core skills in robotics and embedded systems by having them solve problem statements that are gamified instances of real world problems termed "themes." A theme contains a series of tasks culminating in a final implementation of a theme with continuous mentoring and progress evaluation. Using the model, students were successfully trained in Image Processing (Krithivasan et al., 2016), 3D modelling and Designing (Karia, 2018) and much more.

Following the same model, a complex theme entitled **Hungry Bird** was introduced in eYRC 2018 which aims to teach participants a general understanding of control system design by Waypoint navigation using parallel PID controllers on an external control loop based on marker-based localization to command velocity of a nano-drone in reference to its pitch, roll, yaw and throttle. Participants were taught marker-based localization using WhyCon (Nitsche, Krajnik, Cizek, Mejail, & Duckett, (2015) and ArUco (Babinec, Jurišica, Hubinský, & Duchoò, (2014) markers, Computing global path using OMPL (Sucan, 2012), Waypoint navigation using PID controller (Åström, 1995) and methods to tune PID parameters. The competition also aims to give students exposure towards Scripting languages such as Python and Lua, open source simulation platform V-REP (Rohmer, 2013) and middleware, ROS (Quigley et al., 2009). This theme was also an experiment in auto evaluating submissions of a large number of students. This paper focuses on the design aspects of tasks and learning outcome of this theme.

This theme showcased the diligence of parent birds by conveying a story of a bird feeding its young. A drone represented the bird whose job was to autonomously fly through a series of (hula) hoops to signify gathering and subsequently feeding fledglings. This paper describes how we designed and deployed these concepts as a series of tasks. Each task aims to impart certain skills which helps the participants to solve the Final problem statement.

28,976 students registered for the competition in teams of 4 thus amounting to 7244 teams from colleges across India, Nepal and Bhutan. The teams have to first pass a selection test which tests them for knowledge of basic electronics, basic programming and aptitude. Following this shortlisting criteria, 1544 teams qualified to participate in the competition out of which 208 teams were assigned this theme.

COMPETITION DEPLOYMENT AND INSIGHTS GAINED

The Hungry Bird theme was conducted in two stages as illustrated in Figure 1.

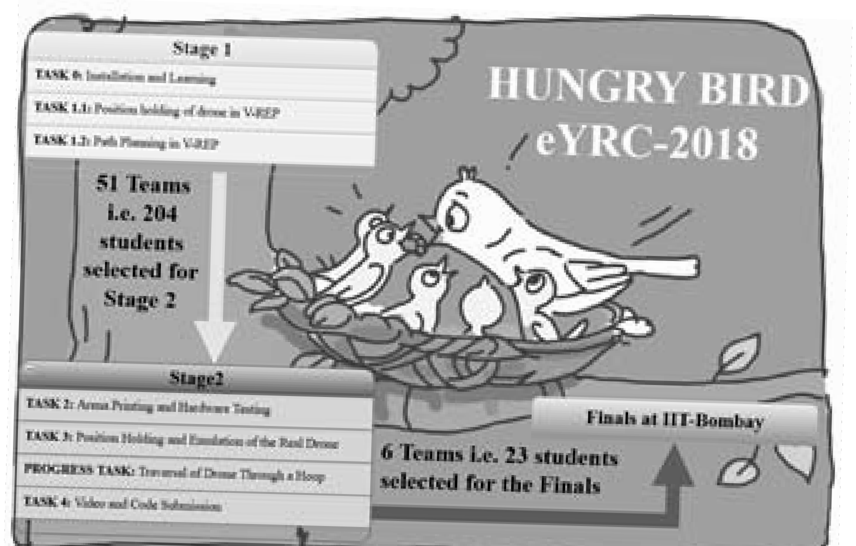

Figure 1: Hungry Bird Theme Format and Statistics

Stage 1 : Participants compete using a drone model in a Simulator

Stage 1 consists of two tasks, viz., Installation and Learn (Task 0) and Implementation of the theme in the simulator, V-REP (Task 1).

Task 0 : Installation and Learn

This task aims to introduce participants to Robot Operating System (ROS) and V-REP (Virtual Robotics Experimentation Platform). Participants are taught about the Marker Based Localization system using Whycon and ArUco markers. Tutorials to learn Linux, Python, Basics of ROS and V-REP[1] and ROS packages[2] for interfacing V-REP and ROS, WhyCon and ArUco markers were provided to the teams. The task involves computing position of WhyCon and ArUco markers using the feedback from an overhead vision sensor in V-REP. The task was graded in a binary way if they have successfully displayed the output or not.

Figure 2: Drone model in V-REP

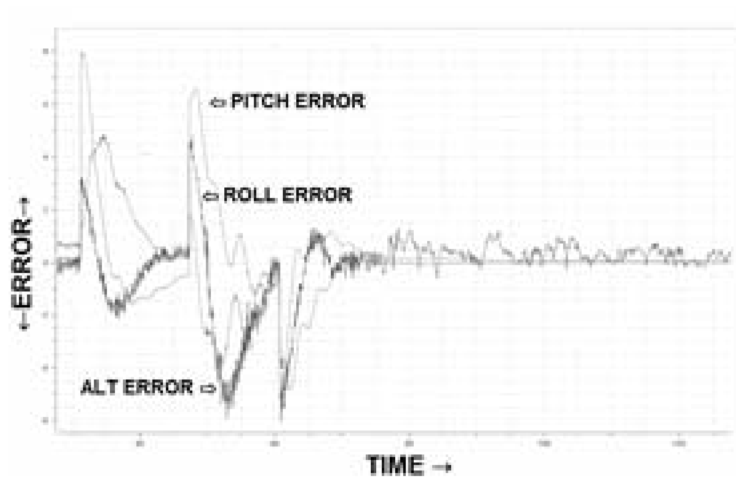

Figure 3: Plotting errors for debugging

Task 1 : Implementation of the theme in the simulator, V-REP

Task 1 consisted of two sub-tasks, viz., Position holding of drone in V-REP (Task 1.1) and Path planning in V-REP (Task 1.2).

Task 1.1 : Position Holding of Drone in V-REP

This task aims to teach participants about PID control by implementing algorithms in V-REP. A well designed drone model named “eDrone” as shown in Figure 2, which responds to ROS commands, is provided to the team. The task involves implementation of a PID algorithm to control the drone via ROS commands to hold its position at a given setpoint using the Localization system which the participants have learned in Task 0. Video tutorials[3] were provided to learn how to implement the control algorithm and how to effectively tune the PID parameters. Classical PID algorithm and ways to improve the algorithm to the task requirement are

[1] https://youtu.be/l5RDBuIM3U8, https://youtu.be/ioNNvy805-4, https://youtu.be/DylQbGCF5ps, https://youtu.be/WB0zCufrHOM

[2] https://github.com/fayyazpocker/vrep_ros_interface, https://github.com/lrse/whycon, https://github.com/pal-robotics/aruco_ros

[3] https://youtu.be/BJ-hkJ2kdR4, https://youtu.be/7KcMoazeeTM, https://youtu.be/SNO_Vm7bpio

also taught. They are taught how to interpret the effectiveness of the algorithm using real time plotting of errors as shown in Figure 3**.** Use of Ziegler-Nichols (Ziegler, 1942) method to tune PID parameters and in-flight tuning of PID parameters using ROS topics are also taught.

Teams were instructed to submit a log file (rosbag) which contains information of the pose of the drone throughout the run. The log file was automatically evaluated based on an algorithm which takes the parameters like time taken by the drone to reach the setpoint, overshoot of the drone from setpoint and stability of the drone at setpoint. Code submitted by the teams were evaluated based on computation of error, Proportional, Derivative and Integral Term in PID and Sampling time of PID. This task comprised 40 marks of which 20 marks were based on automatic evaluation of the rosbag file and 20 marks were based on evaluation of code.

Task 1.2 : Path planning in V-REP

This task helps participants learn to compute global path using OMPL plugin available in V-REP. A V-REP scene as shown in Figure 4 with obstacles and target locations are provided to teams. The task is to control the drone to reach each target point represented by blue, green and red spheres whilst avoiding obstacles. Required video tutorials[4] for the completion of the task were provided. Learnings in Task 0 and Task 1.1 will help in completing this task. Similar to Task 1.1, the log file submitted by the participants were used for automatic evaluation of the submission considering parameters like time taken by the drone to cover all targets, the number of targets the drone covered and the deviation from the optimal path. This task comprised of 60 marks out of which 40 marks were based on automatic evaluation of rosbag file and 20 marks for code evaluation. Cumulative marks of Task 1.1 and Task 1.2 were considered for selection for Stage 2. Figure 5 shows mark distribution graph for Stage 1 of 208 teams. The cut off for selection to Stage 2 was set to 50 marks. Out of 208 teams, 51 teams got selected.

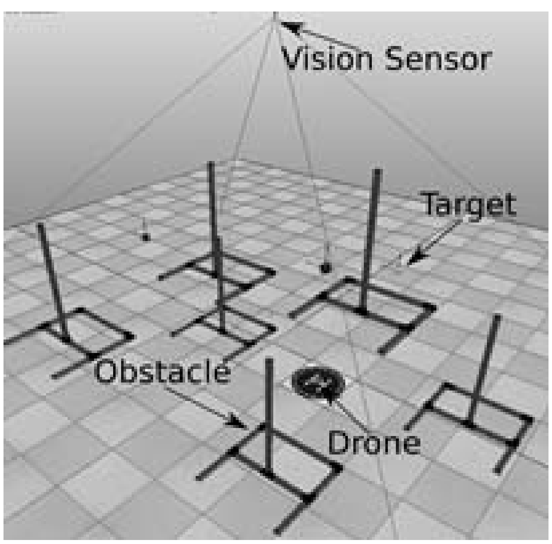

Figure 4: V-REP scene for Task 1.2

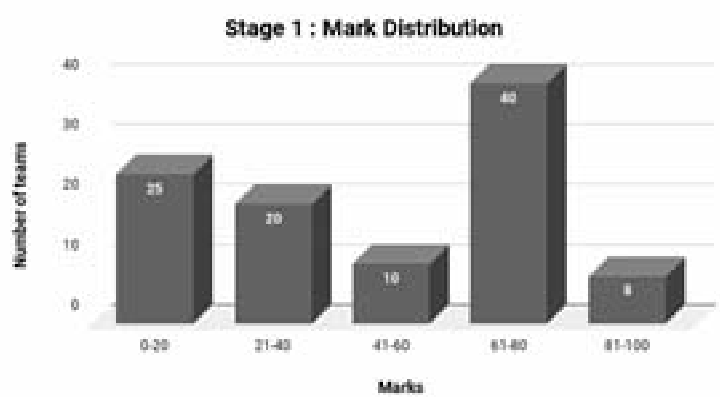

Figure 5: Mark distribution in Stage 1

[4] https://youtu.be/F9U-cCAoBM8, https://youtu.be/beHLO-E6bgI

Stage 2 : Participants compete with given drone kit

Stage 2 consisted of four tasks, viz., Arena Printing and hardware testing (Task 2), Position holding and emulation of real drone (Task 3), Traversal of drone through a hoop (Progress Task) and Video and Code submission (Task 4). The selected teams were sent a PlutoX drone[5] along with hula hoops. PlutoX drones are connected wirelessly to a laptop and controlled using ROS commands, same as how a drone model is controlled in V-REP in Stage 1. Teams are given a Rulebook[6] which gives detailed rules and information regarding theme implementation. It describes how to set the arena, rules to be followed and a formula to be used to evaluate their submissions. The arena is a representation of a Jungle as shown in Figure 6. The drone termed “Bird” must navigate through hula hoops of different colours which represents different types of trees based on the feedback from a camera placed at ceiling height as shown in Figure 6.

Task 2 : Arena Printing and Hardware Testing

In this task, teams print the given arena on a flex sheet and setup the arena as per the Rulebook. Teams were provided with sample videos and manuals to test the drone. This task aims to teach the participants pose estimation of hoops using ArUco markers. They were given a task to programmatically emulate hoops set in a given position and orientation in real world into V-REP, on completing which they had to submit a screenshot having both image output from the overhead camera and the top-view of the V-REP scene as shown in Figure 7. This task carried 20 marks & was graded based on successful emulation of hoops.

Task 3 : Position Holding and emulation of real drone

This task aims to teach the participants implementation of PID algorithm on a real drone. In this task teams had to implement Task 1.1 with a physical drone. They have to hold the position of the drone at a given setpoint with reference to WhyCon frame i.e. [0,0,20] as shown in Figure 8. They also had to emulate the drone in V-REP using what they learnt in Task 2. Students also had to submit an assignment answering various technical and implementation related questions. The submission criteria and evaluation method were the same as Task 1.1. This task comprised of 100 marks out of which 60 marks were based on the automatic evaluation of rosbag file, 10 marks to successful emulation in V-REP and 30 marks for the assignment**.**

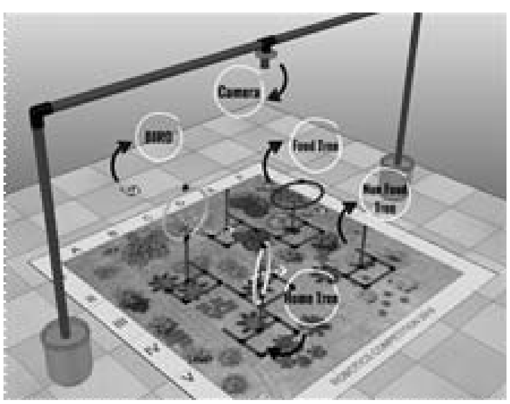

Figure 6: Hungry Bird arena setup

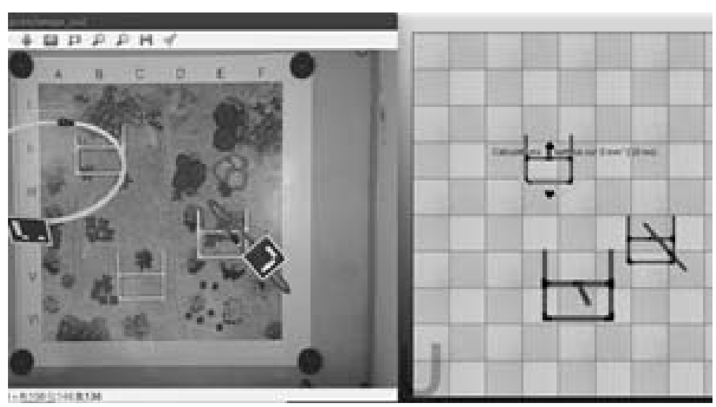

Figure 7: Emulation of real world in V-REP

5 https://www.dronaaviation.com/plutox/

6 https://drive.google.com/file/d/1IPPPzwfyCT0YsWydXEgytTdhSYa_iDfH/view?usp=sharing

Progress Task : Traversal of drone through a hoop

This task aims to teach the participants waypoint navigation of Nano drone through each path points in the generated global path. In this task, the teams are to control the drone to steer it through a hoop set at a given position and orientation as shown in Figure 9. The task carries 100 marks and was graded on the basis of the time taken to complete the task, emulation of the hoop using an ArUco marker, emulation of drone using a WhyCon marker, computation of the path and the number of collisions.

Figure 8: Position holding of Drone in Task 3

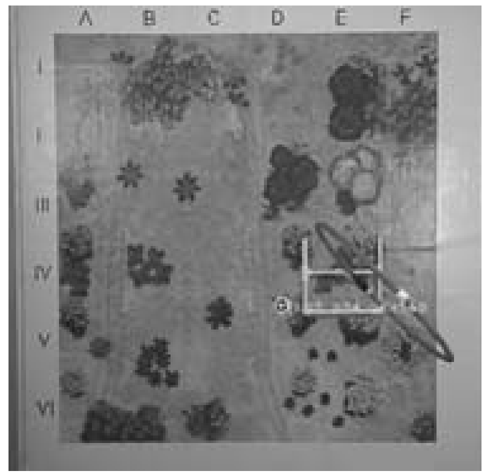

Figure 9: Traversal of drone through hoop

Task 4 : Video and Code Submission

In this final task of the competition, teams had to upload a video demonstrating their solution. Two configurations of arena setup were provided, one with less number of traversals and obstacles and a harder, optional bonus one. A run is considered successful if the drone traverses through hoops as per the given configuration without any collision. This task was graded based on a formula specified in the rulebook and evaluation of the final code. Cumulative marks of Task 4 and Progress Task were considered for selection in Finals.

Finals : Demonstration of theme at IIT Bombay

Six teams that demonstrated the best run (using the formula given by us in the Rulebook) for both configurations were chosen as Finalists to compete the Finals held at IIT Bombay.

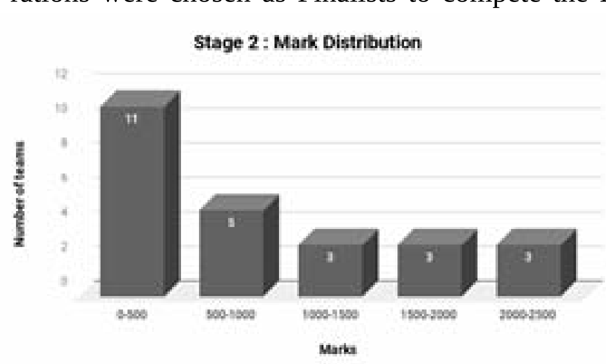

Figure 10: Mark distribution in Stage 2

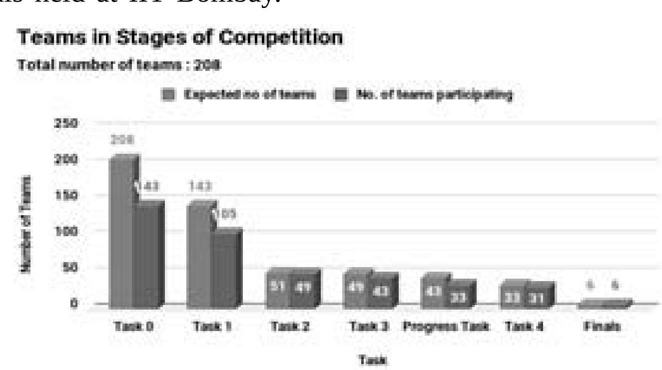

Figure 11: Teams in stages of the competition

ANALYSIS OF IMPACT AND EFFECTIVENESS

The primary objective of this competition was learning control system design and navigation using Nano-drone. Through this theme, students are given exposure towards Linux, Python, Lua, ROS, V-REP, PID tuning and automatic path planning.

We started with 208 teams for Hungry Bird theme. Figure 11 presents details of the number of teams participating in various stages of the competition. Expected numbers of teams are those who have made submissions of previous tasks. For instance, In Task 1, there are 143 expected teams as they have submitted the previous task, Task 0. 51, i.e. 24.51%, of the total teams selected for the theme were shortlisted for Stage 2. Hence 51 teams are expected to submit Task 2. As six teams were to be chosen as finalists, the expected number of teams for finals are six. Number of teams participating are the teams who have made a submission for the corresponding tasks.

Level *	Level Description *	Task	Skills Acquired
Imparting Knowledge	Recognition and understanding of facts, terms, definitions, etc.	Task 0: S/W Installation and Getting familiar with V-REP and ROS	• Installation & basic learning of V-REP and ROS • Learning Pose estimation using WhyCon and ArUco markers
Application of Knowledge	Use of knowledge in ways that demonstrate understanding of concepts, their proper use, and limitations of their applicability	Task 1.1: Position holding of Drone Task 1.2: Path planning in V-REP	• Implementation of PID to control drone in V-REP • Waypoint navigation of drone in V-REP • Learn to compute global path using OMPL
Critical Analysis	Examination and evaluation of information as required to judge its value in a solution and to make decisions/ selection of technology accordingly	Task 2: Arena printing, Hardware Testing Task 3: Position holding and emulation of drone	• Implementation of PID controller on a real drone • Real time emulation of drone in V-REP
Extension of Knowledge	Extending knowledge beyond what was received, creating new knowledge, making new inferences, transferring knowledge to usefulness in new areas of applications	Progress Task: Traversal of drone through a hoop Task 4: Video and Code Submission	To have a final working demo of the drone traversing through the hoops with given configurations

Table 1: Mapping level of learning outcomes to Tasks and Statistics

* Levels and Description of levels are taken from (Davis et al, 1997)

Table 1 summarizes the knowledge imparted to the participants from the competition in each task. Table 1 and Figure 11 shows that 68.75%, i.e. 143 out of 208 teams, have learned the basic concepts of ROS and V-REP. It also shows that 50.48% of total teams, i.e. 105 out of 208 teams, have participated actively in Stage 1 and have implemented PID controller to navigate the drone through the computed path in the Simulator. 24.5%, i.e. 51 out of 208 teams, had hands-on-experience with a real drone. 60.8%, i.e. 31 out of the selected 51 teams, actively participated throughout the remaining tasks and made final submission. It is interesting to note that once the student teams qualified for Stage 2, more than 75% participated throughout the tasks indicating less number of dropouts compared to Stage 1.

To learn the effect of our theme on the participants, we took feedback from them at the end of Stage 1 and Stage 2. 451 out of 832 and 141 out of 204 participants gave responses for Stage 1 and Stage 2 feedback respectively. Figure 12 shows that 77.8% of participants who have responded to the feedback feel that the tutorials were efficient enough to cover all the relevant topics involved in the theme. Figure 12 also tells that this theme has helped 86% of participants to have a better understanding of all the concepts and tools involved in the theme. Even though according to Figure 13, 71.6% of participants found the tasks difficult, more than 50% of the total teams have actively participated in Stage 1. This indicates that the tutorials and the guidance the participants received from Piazza was able to help them overcome these difficulties. 73.5% of participants (Figure 13) who feel that the response of the mentors from Piazza helped them to solve tasks further establishes that fact.

Students were also asked what were the most important things they liked about the competition. Many of them liked the way in which the problem statement was split into different tasks and the fact that completion of each task helps in bringing them a step closer towards solving the final problem statement. Apart from gaining technical knowledge, participants says that the competition helped them gain skills like team spirit, time management and leadership qualities.

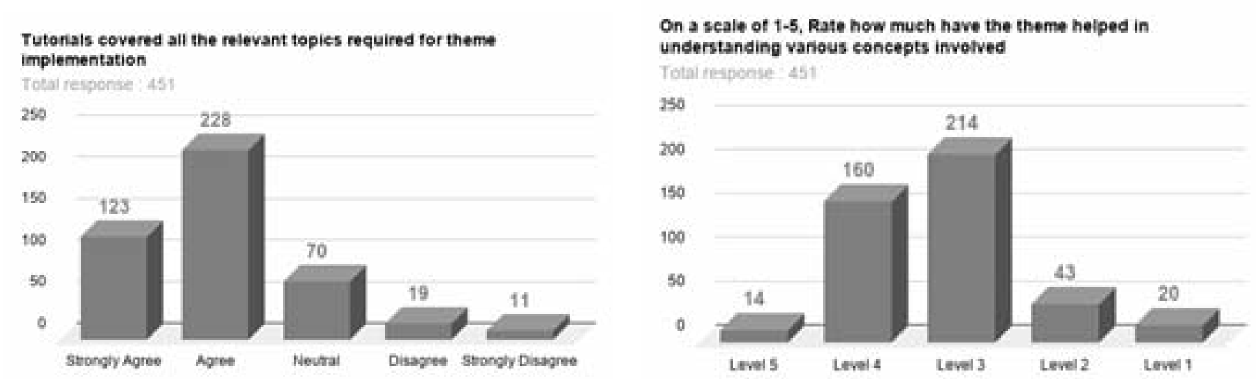

Figure 12: Responses from survey conducted after Stage 1

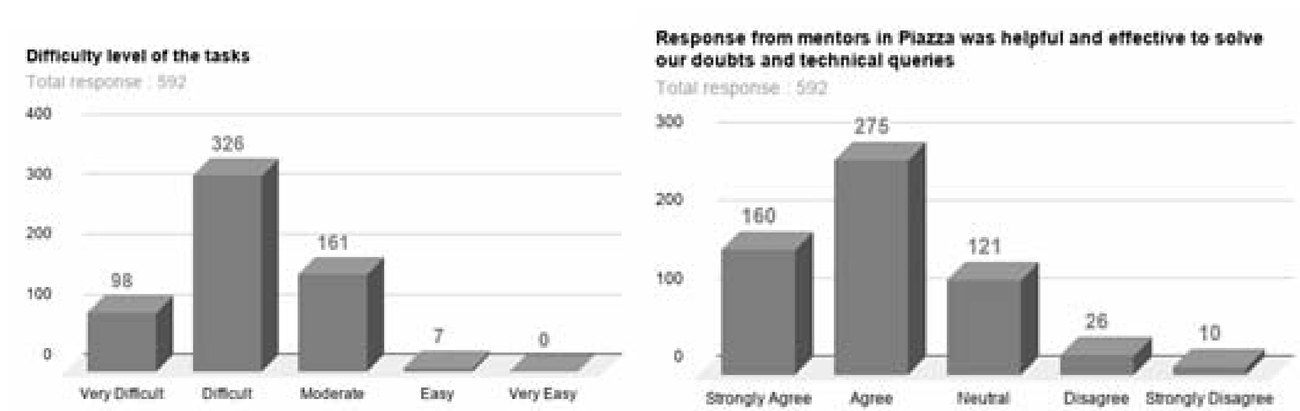

Figure 13: Responses from survey conducted after Stage 2

CONCLUSION

The analysis and the feedback from the participants validates the effectiveness of our ICT-enhanced, project based learning approach. It shows that the participants through the competition had a better understanding of control algorithms and have learned tools like V-REP and ROS. Exposure towards such platforms can help them in future to validate a project in a simulator and then implement it in the real world. Also, the model of splitting the project into various tasks can help participants to address a problem or project in a similar way in future. Alongwith effectively imparting technical skills, the competition also helps in improving team spirit and leadership skills. As most of the tasks are automatically evaluated, the model also opens up the door to scale the competition to a large number of students and we are hoping to teach college students at an ever larger scale in forthcoming editions of the e-YRC. Our success is seen in the participation levels since the competition began in 2012. Registrations have grown as follows: 4384, 6324, 12428, 19568, 22608, 23728 to 28672 registrations in 2018 - in spite of a 30% YoY reduction in engineering college seats since 2015.

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EXPLORING ANGLES IN A PROGRAMMING ENVIRONMENT

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In this paper, we describe the results from a whole-class design experiment in a sixth-grade classroom where students explored angles through activity in Scratch programming. The retrospective data analysis shows that through this programming activity students were able to form advanced generalizations about angles that are not accessible with the static representations of angles on paper. These findings illustrate the power of dynamic programming environments for transforming students' reasoning about angle measurement.

INTRODUCTION

The understanding of angles is foundational for working with other geometric concepts such as polygons, symmetry, transformations, and for developing arguments in geometric proofs. Even though angles are essential in understanding many aspects of mathematics, students continue to struggle in understanding this concept. Previous research has found that young students develop a variety of misconceptions with regards to angles. Examples include students reasoning that an angle measure depends on the length of its sides (Smith, King, & Hoyte, 2014), or that an angle only goes counter-clockwise (Mitchelmore, 1998), or that the word 'angle' evokes a 'right angle' prototype (Devichi & Munier, 2013).

Smith et al. (2014) argued that students develop these misconceptions because angles are introduced using static representations on paper. Students are often expected to reason about the figural aspects of geometric objects when they are asked to work with the appearance of a static drawing (Hollebrands, 2003). Mitchelmore (1998) differentiated between *dynamic angles* as illustrating the motion of opening or rotation from *static angles* as the result of that motion. Research has shown that when students work with dynamic angles, for example, by modelling angles using physical body rotations (Smith et al., 2014), they can abandon their misconceptions about angles (Devichi & Munier, 2013). In addition to physical motion, students can experience dynamic angles through dynamic geometry environments (DGEs). Hardison (2018) found that when angles are presented in a DGE (e.g., Geometer's Sketchpad [GSP]) they can reason about angles as an amount of rotation. In learning geometry, it is important for students to work with figures rather with a drawing (Parzysz, 1988). When students work with digital environments, they can control or manipulate mathematical objects and identify invariant features and mathematical relationships (Hollebrands, 2003). We believe that this is the kind of reasoning that would help develop students' figural understanding of angles.

Research on technological tools shows that students adapt their understanding of a geometric object consistent with the functionalities afforded by the computer environments (Hollebrands, 2003). Studies using GSP treat angle as a property of geometric shapes (e.g., Hollebrands, 2003) or as a concept to be quantified (e.g., Hardison, 2018). For example, in GSP, a student can create a parallelogram by constructing two pairs of congruent parallel sides and verify this parallelism using angle measure. On the other hand, research on early programming environments, such as Logo programming (Papert, 1980), provided evidence that the programming environment helped students to pay attention on the direction of a turn and its measurement in degrees (e.g., Clements & Battista, 1989). For instance, students constructed a parallelogram using commands such as FORWARD motion and RIGHT turn (Clements & Battista, 1989) and reasoned about angles as the amount of turn. Additionally, the role of the Logo environment was significant for students to understand turns as conceptual objects involving iterations and directionality and construct dynamic rotations imagery (Clements, Battista, Sarama, & Swaminathan, 1996). Although exploring angles in a programming environment was found to be beneficial for students to actively construct a dynamic conception of angles, the Logo programming language was perceived as "too difficult to impact mathematics learning" (Hoyles & Noss, 1992) and discouraged further research on using Logo.

Scratch (www.scratch.mit.edu), a recent development on programming environments built based on the constructionist perspective of Logo (Papert, 1980), allows students to program interactive projects using a drag-and-drop, and snapping blocks system that encourages young students to program even without any prior programming experience (Maloney, Resnick, Rusk, Silverman, & Eastmond, 2010). Previous research on exploring students' activity in Scratch programming tasks showed that Scratch makes learning engaging and meaningful to students (Maloney, et. al., 2010) and can support students' mathematical reasoning (Benton, Hoyles, Kalas, & Noss, 2016). For instance, Calao, Moreno-León, Correa, & Robles, 2015) found that students who engaged with Scratch activities in their mathematics class have increased their understanding of mathematical concepts and processes. Considering the above, Scratch programming opens up a new opportunity for studying students' angle reasoning. Although some of these studies incorporated angles in their task design, angles are used as input values for commands on the amount of turn (e.g., Benton et al., 2016), but not focusing on students' reasoning. Consequently, our goal was to examine students' reasoning about angles as in a Scratch programming task and that this task is relevant to students' daily experiences. More specifically, we explored the following research question: How do students reason about angles as a result of their engagement with the programming task on Scratch?

METHODS

In this paper, we present a whole class design experiment (Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003) with sixth-grade students working on a Scratch task. We used a design experiment methodology to engineer particular forms of reasoning within the context of angles and investigate how these forms of reasoning developed through students' engagement with our designed task on Scratch.

DESIGN AND CONJECTURES

The students involved in this study did not have any prior experience with Scratch. Therefore, we introduced them to some basic elements of the Scratch interface (Figure 1). First, students learned about the *Sprites*. The sprites are the programmable objects that perform the actions on the *Stage*. For instance, we used an image of an artificial satellite as one of the sprites to be programmed using the *Blocks*. These blocks, organized in the *Blocks Palette*, contain programming syntax and are shaped into puzzle-pieces that can be dragged to the Scripts Area. Also, Scratch blocks can be vertically snapped together to form a script. Part of the task is for the students to observe how the arrangements of blocks matter to the intended output. Scratch executes the codes following the order of blocks snapped vertically or wrapped by other blocks (e.g., Forever, Repeat) that repeat the commands inside the loop. We explain the difference between these two arrangements in the following paragraphs.

Figure 1. The Scratch interface

We designed the task "Satellite orbits the earth" (https://scratch.mit.edu/projects/196121316/) after the students have completed a module on Orbit in their science class, aiming to relate the programming task to the content they have been exploring in science. In the task, the students were asked to make the artificial satellite sprite move around another sprite, the earth, in orbit. For the satellite sprite to orbit the earth sprite, students need to create a script that moves the satellite for a short distance (e.g., 15 steps) and turns it for one degree using 360 repetitions, defining in that way a circle as a polygon with 360 sides. Our goal was to provide opportunities for students to see the purpose and utility of mathematics (Ainley, Pratt, & Hansen, 2006), specifically of angle measurement, to complete the programming task.

We asked the students to use our pre-selected blocks in Scratch to direct their attention on a particular mathematical idea embedded in the blocks (see Scripts Area in Figure 1). Similar to Logo's FORWARD or BACK (steps) and RIGHT or LEFT (turn) commands (Clements & Battista, 1989), the Scratch blocks also offer students to focus on the translation and direction of turn. Specifically, the syntax of the "move_steps" block moves the sprite a specific value for a translation (positive or negative) while the "turn_degrees" block changes the direction on which the sprite is facing. Scratch executes the value in "turn_degrees" block using the external angle. Hence, a combination of these two blocks can make the sprite move and turn. For example, the script “move 50 steps, turn 90 degrees, move 50 steps, turn 90 degrees, move 50 steps, turn 90 degrees, move 50 steps, turn 90 degrees” will create a square movement. The “Repeat _” block can be used to make the same square using a shorter script (Repeat 4[move 50, turn 90]). The “Forever” block infinitely repeats the script within the loop until the stop sign is clicked. The block “when (flag) clicked” starts the simulation, while “pen down” and “clear” tracks the path of the sprite and erases it, respectively.

Analysis

At the end of the experiment, we conducted a retrospective analysis to identify episodes when students focused on a particular mathematical idea or discourse (Cobb et al., 2001) in the context of angles. Then, we reanalysed these episodes to identify potentially reproducible patterns (Cobb et al., 2003) on angle reasoning as a result of students’ interaction with the task and their social sharing process in a programming activity (Papert, 1980). Specifically, our analysis was guided by themes related to turns, such as the iteration and directionality, and the role of the computer environment for developing turn concepts and dynamic rotations (Clements et al., 1996). In this paper, we present episodes of one pair of students, Paul and Laura, working on the task aiming to provide an example of the forms of reasoning that students’ exhibited.

RESULTS

We describe some forms of reasoning about angles that students exhibited as they interacted with our task. We discuss those by giving examples from four episodes from our conversations with some students.

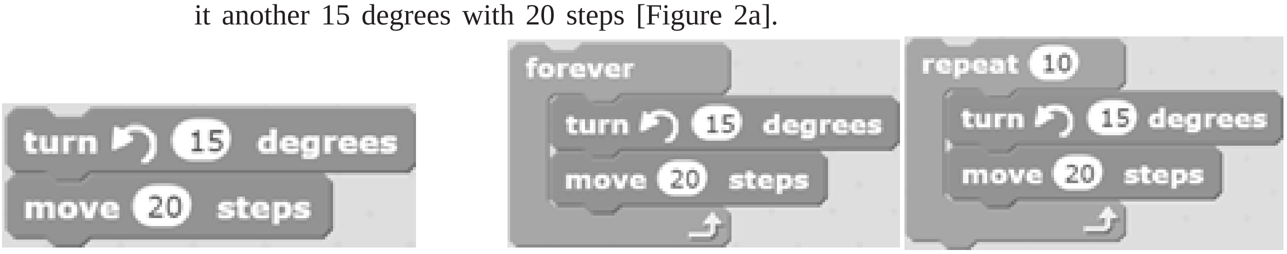
Episode 1: Exploring angles as turns

Students first explored the pre-selected blocks found in the Scripts Area, tried different values on the blocks and observed the change in the output. When students used only the “turn_degrees” block, they noticed that the satellite sprite was only turning in place. When they tried only the “move_steps” block, they observed that the sprite is only moving on a straight line. Therefore, they decided to combine the two blocks to observe a different output. For instance, Paul discussed his initial attempt on moving the satellite around the earth sprite:

Paul: I made it rotate!

Researcher: How did you do that?

Paul: I put it at 15 degrees that way and I put the rotation, say left to right. And then, I turned it another 15 degrees with 20 steps [Figure 2a].



(a) (b)

Figure 2. Paul’s script (a) before the Repeat block, (b) after the Repeat or Forever blocks

Similar to Paul, students first observed the change in the sprite when the “move_steps” and “turn_degrees” blocks are clicked individually or snapped together (Figure 2a). Connecting the “turn_degrees” and “move_steps” blocks creates a syntax using the mathematical concepts of translation and angles to move and turn the sprite. By exploring different ways to rotate the satellite and identifying the constraints of their script (snapping the two blocks together only moves the sprite once), they started building more complex scripts. For instance, Paul identified that snapping the blocks together within the Repeat or Forever block would result in the iteration of the code (Figure 2b).

Researcher: How does it work?

Paul: When I covered it [“move_steps” and “turn_degrees” blocks] with all these [Repeat and Forever blocks], it made it [sprite] repeat each one several, several times.

Researcher: How many times?

Paul: Like ten, all of these [“move_steps” and “turn_degrees” blocks]. And then it [Forever block] made it [satellite] go on and on in this one [the blocks inside the Repeat block]. So, the special, it [Forever block] makes it go forever, these ten steps. So, when I got to this, it just kept going out.

Paul built a more complex script by experimenting with the control blocks while identifying the need (Papert & Harel, 1991) to iterate the turns and create a motion of a continuous dynamic rotation (Clements et al., 1996).

Episode 2: Expressing angle relationships

In multiple instances during the design experiment, students were asked to describe what they have learned from working with the task and articulate the reasons behind their approach. In the following excerpt, Paul was trying to make the satellite to rotate by experimenting with the “turn_degrees” and “move_steps” tools.

Paul: It would turn that way.

Researcher: Why is it turning that way?

Paul: It’s turning this way. And it’s slowly orbiting.

Researcher: Why is it rotating like that? What do you think?

Paul: Because the degrees are too small.

Similar to Paul, students were able to generalize that the smaller the degree angle in the “turn_degrees” block (if the value in the “move_steps” block stays the same), the more time it will take for the satellite to make a full turn (Figure 3).

Another mathematical relationship that the students noticed was that the smaller the value in the “move_steps” block (if the value on the “turn_degrees” block stays the same), the smaller the track the sprite creates and the faster it will make a full turn (Figure 4).

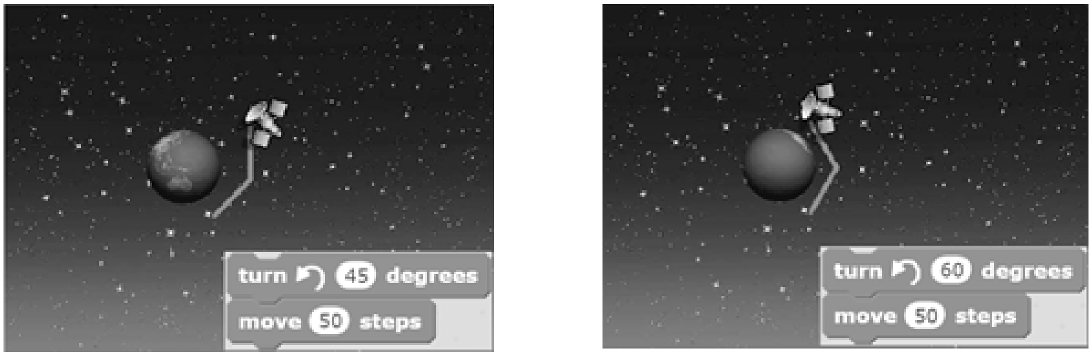
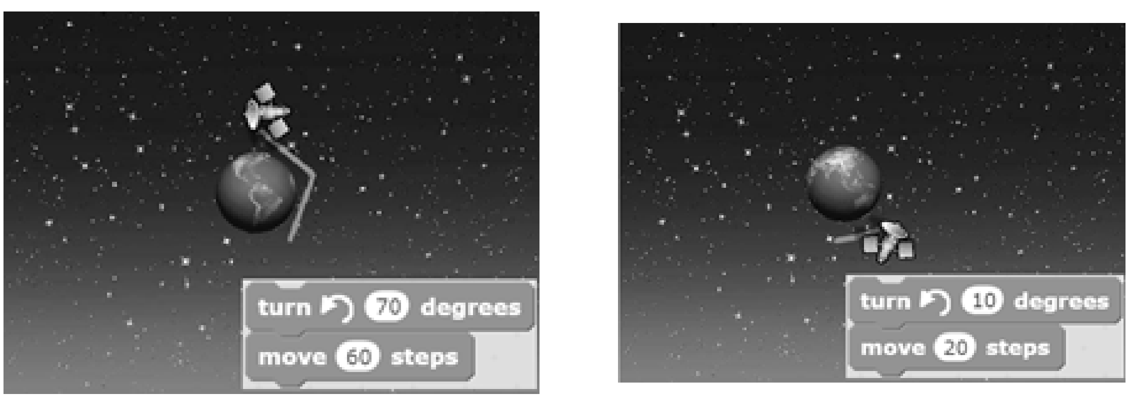


Figure 3. The same value for translation but different degrees of rotation

Figure 4. The same degrees but with different steps

As students discovered that changing the values in the “move_step” block can affect the sprite’s turn, they explored different values for the “turn_degrees” block. These explorations helped students complete the task and make the satellite orbit the earth. By experimenting with different values for steps and degrees, they were able to generalize that a small number of steps and degrees will create a *smooth* circle-like movement around the earth compared to a large number of steps and degrees (Figure 5).



(a) (b)

Figure 5. (a) a large number of steps and degrees **(b)** a small number of steps and degrees

When students tried different degrees turn, they avoided the notion of a right angle prototype (Devichi & Munier, 2013). Also, when they tried different combinations of values for the degrees and steps, students exhibited that they do not consider angles as dependent on side length (Smith et al., 2014).

Episode 3: Constructing codes as formulas

Throughout the design experiment, students exchanged their ideas by collaborating and sharing what they have noticed while working on the task. We encouraged the students to interact with another student while developing their codes. The following conversation between Paul and Laura shows how students compared their work. Although both students successfully moved the satellite to orbit around the earth, their scripts were different.

Paul: Look, look. This is the formula!

Laura: I did it! [Raising right arm].

Paul: [Checking Laura's screen]. Look at mine. Mine [output] is not as fast as yours. But mine does the same job. It gets around the earth.

The excerpt above shows that Paul considered the codes he constructed as the formula to solve the task. Also, Paul compared his codes to Laura's and identified the similarities and differences between their constructed codes (Figure 6). For instance, Paul used a counter-clockwise "turn_degrees" block while Laura used a clockwise block exhibiting the bi-directionality of turns (Clements et al., 1996). By comparing their solutions, students realised that angles can turn both clockwise and counter-clockwise, avoiding the misconception that angles only go counter-clockwise (Mitchelmore, 1998). Paul also used 20 steps in the move block instead of 30 that Laura used, and as a result, his orbit was smoother and slower than Laura's as Paul expressed, "Mine is not as fast as yours." Students' independent explorations provided them opportunities to discover different ways to solve the task while closely attending to how they used the concept of angles in the programming activity.

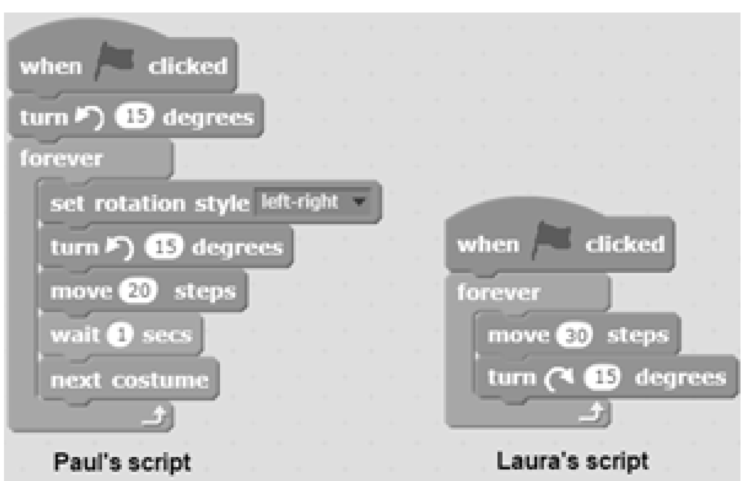


Figure 6. Paul's script (left) and Laura's script (right) for orbiting the satellite

We noticed that while working together to compare their work and answer questions of one another, students developed deeper understanding of mathematical ideas. They conceptualized multiple solutions to a problem by trying to understand how the solution of others work. This social sharing process is one of the benefits of undertaking constructionist activities in computational environments (Papert, 1980).

Episode 4: Connecting ideas about angles

By the end of the experiment, students were able to describe a full orbit as 360 degrees:

> Paul: It moves back from the earth. That's the code. And I'm going to make them like I'm going to stop it, it goes back where it was. There's 360 backflip, it goes back into space from earth. That is what I call science. But I want to do it better.

In addition to his math reasoning about orbit, Paul also made an explicit link to the science context of satellite sent into space from the earth. Similar to Paul, students were able to make connections between concepts used in the programming task with the ideas in mathematics, other disciplines, or even with their everyday lives. When students actively engaged with the designed task on Scratch, they creatively integrated scientific, mathematical, and technological ideas as a learning experience meaningful to them.

CONCLUDING REMARKS

This paper illustrated the potential of a Scratch programming task for developing students' mathematical understanding about angles. Students were able to reason about the effect of the angle measurement in the "turn_degrees" block and the number of steps in the "move_steps" block on the nature of an object's turn. They also utilized the clockwise-counterclockwise motion that an object can follow and identified that 360 degrees makes an object return to its original position. Moreover, the students learned that turns may be constructed differently but can form similar results. Therefore, we consider that integrating relevant programming activities in mathematics classrooms is important in providing opportunities for younger students to explore the dynamic nature of angles and advance their understanding of angles used in other disciplines.

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EXPLORING STUDENTS' ALGEBRAIC REASONING ON QUADRATIC EQUATIONS: IMPLICATIONS FOR SCHOOL-BASED ASSESSMENT

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The first encounter with abstract mathematical reasoning impedes the understanding of algebra for most students at lower secondary education levels, which continues to upper levels and beyond. A descriptive survey research involving 300 grade 11 students of ages 14 to 20 clustered into low, moderate, and high academic performance was conducted. Written responses were collected using a Mathematical Reasoning Test, regarding students' argumentation modes for justifying an algebraic conjecture and assessment of suggested solutions for a given quadratic equation. Chi-square test revealed no significant relationship between students' modes of justification and the type of school they came from, $c^2(4) = .50$, $p =.97$. However, the majority exhibited limited forms of understanding and comprehension of quadratic equations. There is a serious need for more attention to students' algebraic reasoning in school-based assessment of mathematical learning.

Keywords: *Algebraic reasoning; School-based assessment; Quadratic equations.*

INTRODUCTION

Students' success in secondary school mathematics is partly dependent on their understanding of algebra. This could be attributed to the fact that algebraic reasoning allows students to explore the structure of mathematics (Ontario Ministry of Education, 2013). In the Zambian curriculum for secondary school mathematics (Curriculum Development Centre, 2013), algebra is introduced to students at the beginning (grade 8) of their secondary education. At that level, students are expected to begin developing abstract thinking that may be required for their advancement in mathematics and science subjects. However, being their first encounter with abstract mathematical reasoning, understanding of algebra has proved to be a 'thorn in the flesh' for most students at that level. Through personal experience, Greer (2008) narrates:

It is a troubling experience to sit beside an eighth grader who is vainly trying to remember what to do with an algebraic equation and reflect that several more years of frustration lie ahead for that student (p.423).

The narration above partly suggests that such difficulties might be carried over till the end of their secondary education and later at college or university. This is also evident by reports and studies that have highlighted students' limited understanding and comprehension of algebraic concepts at both secondary school (Examinations Council of Zambia, 2018) and tertiary (Mukuka & Shumba, 2016) levels of education. Deriving and solving quadratic equations has been reported by the Chief examiner (Examinations Council of Zambia, 2016; 2018) as being challenging to most of the candidates who sat for Grade 12 national examinations. Besides that, it has been noted that students' difficulties in comprehending algebraic concepts is not unique to Zambia because similar results have been reported in other settings (see Kramarski, 2008; Lucariello, Tinec, & Ganleyd, 2014; Organisation for Economic Co-operation and Development [OECD], 2013; Susac, Bubic, Vrbanc, & Planinic, 2014).

Despite this being the case, none of the research conducted in Zambia has attempted to understand students' algebraic reasoning at secondary school level. Our belief is that understanding students' difficulties relating to algebra at grade 11 level would give teachers enough time to correct the situation before those students complete their secondary school education. In an attempt to addressing those challenges, more efforts especially in the developing world like Zambia could be channelled towards identifying classroom practices that can foster students' algebraic reasoning rather than focusing on promoting memorisation of facts. Greer (2008) and Kaput (1999) have highlighted the forms of algebraic reasoning that are relevant to schools and how school algebra can be taught. Nevertheless, our intention here is to understand students' algebraic reasoning on quadratic equations because none of the studies conducted in Zambia has made such an attempt. Consequently, results of this study will lay a foundation for further research on how the reasoning abilities could be enhanced among learners of algebra and mathematics in general.

PURPOSE OF THE STUDY

This study seeks to understand students' ability to reason logically and to rationalise and/or justify mathematical claims. This paper reports on the results of the analysis of data that was collected from grade 11 students on a mathematical reasoning test involving quadratic equations and functions. In line with the model recently developed by Jeannotte & Kieran (2017) on the "process aspects" of mathematical reasoning, our analysis is guided by the following research questions:

i. What are the modes of argumentation used by students in justifying algebraic conjectures?
ii. How do the students assess and validate other people's solutions of a given quadratic equation?

These questions explore how students reason algebraically. Understanding how students assess and validate other people's solutions of a given equation is important to anticipate how they can generate their own solutions when they encounter similar tasks during school-based or external assessment of mathematical learning.

METHODOLOGY

Participants of this descriptive survey research were 300 grade 11 students aged between 14 and 20

(M = 16.24, SD = .98). A Cluster random sampling method was used to select the participants from six public secondary schools within the Ndola district of Zambia. Schools were grouped into three clusters based on their average academic performance (high performing, moderate performing, and low performing). To ensure the representativeness of the sample, two schools were randomly selected from each of the three clusters. At each of the participating schools, one grade 11 class was randomly selected and all the students from each of the selected classes were included in the sample. Before administration of the questionnaire, permission from the relevant authority (Ministry of General Education Permanent Secretary, Provincial Education Officer, and the District Education Board Secretary) was sought and granted.

All the participants provided written consent and the study had received ethical approval from the Research and Innovations unit of the College of Education, University of Rwanda. Students' written responses were collected via a '*Mathematical Reasoning Test*' comprising of seven (7) mathematical tasks on quadratic equations and functions. However, this paper focuses on two of those tasks. Task one is concerned with students' justifications about the truth of the statement "$x^2 + 1$ *can never be zero if* $x \in R$"**.** Task two tested the students' ability to assess and select the most convincing solution of a quadratic equation $(x+2)(x+3)=14$. The development and analysis of these tasks were in line with the requirements of the Zambian curriculum for secondary school mathematics (Curriculum Development Centre, 2013) and previous studies (Brodie, 2010; Jeannotte & Kieran, 2017) on students' mathematical reasoning. All the tasks were assessed and validated by mathematics educators at different levels.

Students' written responses were analysed into categories of meaning using descriptive statistics. These categories focused on empirical or inductive reasoning versus analytical or deductive reasoning. Justification through inductive reasoning was based on citing numerical values to expressions or giving examples of numbers that can satisfy a given statement or expression. On the other hand, analytical justifications were based on logical deductions to arrive at a valid generalisation of a given algebraic statement or argument. A contingency table (cross-tabulation) and Pearson Chi-square Test were also generated to determine whether students from high performing schools answered questions differently from others. Factors that influenced the modes of argumentation by students were also identified to provide guidance on the potential areas of focus in future studies.

RESULTS

The algebraic reasoning being implied here is linked to students' ability in making justified inferences with conjecturing, generalisation and justification being central to the reasoning process (Mata-Pereira & da Ponte, 2017). In that respect, students' algebraic reasoning was assessed based on two categories namely, inductive and deductive reasoning.

Students' argumentation modes for justifying an algebraic conjecture

Students were provided with the following statement:

"$x^2 + 1$ *can never be zero***"**.

Students were then asked to state whether the statement was true or false for real values of *x* and to construct valid explanations to justify their choices. Two hundred thirty-seven (237) students representing 79% agreed that the statement was true and only 33 (11%) indicated that the statement was false, while 30 (10%) of the students did not respond to the question. All the students who indicated that the statement was false attempted to substitute –1 for *x*. In their own thinking "$-1^2 + 1 = 0$" This reflects students' inadequate understanding about substituting numerical values in a given algebraic expression and their failure to square negative numbers.

A follow-up analysis of 237 submissions representing 79% of students who concurred that the statement was true revealed categories of meaning displayed in Table 1. Results show that the majority (n = 120 or 51%) justified their choice with explanations that were out of context. This was followed by those who gave explanations that were classified as inductive reasoning (n = 83 or 35%) while very few (n = 34 or 14%) argued deductively.

A further qualitative analysis of students' explanations indicated that 90 (75%) of those whose justifications were classified as "out of context" had misconceptions about real numbers. They treated real numbers as mere natural numbers. The remaining 30 (25%) of the respondents gave different explanations without any reference to real numbers. The following submissions by two of the respondents reflect such misconceptions: Respondent 1: The statement is true because real numbers are all positive like 1,2,3,4, etc. Picking any number and add 1 cannot give zero.

Respondent 2: The statement is true because of addition of 1. If it was subtraction, it can be zero because 1-1 = 0.

On the other hand, those who argued inductively justified their choices by citing specific integers or natural numbers to inform their conclusions. It was also established that all of those who argued inductively appeared to have mistaken real numbers for integers or natural numbers because none of them cited other forms of rational numbers (such as decimals or common fractions) or irrational numbers.

Among the 14% who were able to justify deductively, 28 (82%) of them explained that whatever real number may be substituted for *x* whether negative or positive, the square of such a number will always be positive. When that positive number is added to 1, the result will always be greater or equal to 1. The remaining 6 (18%) of those respondents made an assumption that $x^2 + 1 = 0$. When they tried to solve this equation, they reached a stage where they could not compute the square root of –1 and concluded that $x^2 + 1$ can never be zero for real values of *x*.

Table 1 also displays the variations in students' argumentation modes (deductive, inductive and out of context) across the three clusters of school average performance levels. Results indicate that 67 (69%) out of 97 respondents from low performing schools agreed that the statement was true. Of this number, 36 (53.7%) justified their choices with explanations that were classified as out of context while 22 (32.8%) justified inductively and only 9 (13.4%) used the deductive mode of argumentation.

Students' argumentation modes		**School average performance levels**			**Total**
		low	*moderate*	*high*	
Out of context	*Count*	36	47	37	120
	% within school average performance level	53.7%	50.5%	48.1%	50.6%
Inductive	*Count*	22	33	28	83
	% within school average performance level	32.8%	35.5%	36.4%	35.0%
Deductive	*Count*	9	13	12	34
	% within school average performance level	13.4%	14.0%	15.6%	14.3%
Total responses	*Count*	67	93	77	237
Total sample		**97**	**122**	**81**	**300**

Table 1: Students' argumentation modes according to school average performance level

Results further indicate that 93 (76%) of the 122 respondents from moderate performing schools agreed that the statement was true. Forty-seven (or 50.5%) of those respondents gave explanations that were classified as out of context while 33 (35.5%) argued inductively and only 13 (14.0%) used a deductive mode of argumentation. Finally 77 (95.1%) of the 81 respondents from high performing schools agreed that the statement was true. Among those responses, 37 (48.1%) justifications were out of context while 28 (36.4%) used inductive reasoning and only 12 (15.6%) used deductive reasoning.

Overall these results indicate that the majority of students from high performing schools (95.1%) rightly recognised the statement as valid compared to 76% of those from moderate performing schools and 69% of the respondents from low performing schools. Based on the results displayed in Table 1, a Pearson Chi-square test was performed to find out whether there was any significant relationship between the way students justified their choices and the type of school they came from. The Pearson Chi-square test in SPSS version 20 showed no significant association between the two categorical variables, $\chi^2(4) = .50, p = .97$. Although many other factors might have contributed to students' inadequate understanding of quadratic equations, it suffices to say that the way teachers taught and assessed them might have led to such a quality landscape in providing valid mathematical justifications regardless of the school average performance level from which respondents were drawn.

Assessment of the suggested solutions for a given quadratic equation

Respondents were presented with the following solutions for a quadratic equation $(x+2)(x–3)=14$.

Solution A

$$(x+2)(x-3)=14$$
$$x+2=14 or x-3=14$$
$$x=14-2 or x=14+3$$
$$x=12 or x=17$$

Solution B

$$(x+2)(x-3)=14$$
$$x^2-3x+2x-6=14$$
$$x^2-x-6=14$$
$$x^2-x-20=0$$
$$x^2-4x+5x-20=0$$
$$x(x-4)+5(x-4)=0$$
$$(x+5)(x-4)=0$$
$$x+5=0 or x-4=0$$
$$x=-5 or x=4$$

Solution C

$$(x+2)(x-3)=14$$
$$x^2-3x+2x-6=14$$
$$x^2-5x-6=14$$
$$x^2-5x=20$$
$$x^2-5x-20=0$$
$$x=\frac{-b\pm\sqrt{b^2-4ac}}{2a}$$
$$x=\frac{-5\pm\sqrt{-5^2-4(1)(-20)}}{2(1)}$$
$$x=\frac{-5+\sqrt{-25+80}}{2}$$
$$x=\frac{-5+\sqrt{55}}{2} or \frac{-5-\sqrt{55}}{2}$$
$$x=1.21 or x=-6.21$$

Table 2

Respondents were then asked to assess each of the three solutions and indicate whether it was correct or wrong. They were also required to justify their choices and to provide their own solutions in an event where they found that all the three given solutions were wrong. Only 17 students representing 6% were able to dismiss all the three solutions and provide valid justifications for their solutions.

Among the 276 students who assessed solution A, 186 (64.4%) rightly identified it as a wrong solution although most of them (97%) could not justify why the solution was wrong. The few (3%) that managed to justify their choices indicated that factors on the left hand side were not supposed to be equated to 14 as that would be the case only if the right hand side was represented by zero. Those who rated solution A as being correct (n = 90 or 32.6%) had a misconception that it was okay to equate each of those factors on the left hand side to 14. They made such a wrong choice even without trying out whether those solutions fitted into the given equation. This could be another indication that students did not understand the property that $x = p$ *or* $x = q$ if and only if $(x–p)(x–q) = 0$ for real numbers p and q.

Of the 263 respondents who managed to assess solution B, 148 (56.3%) of them rightly recognised it as a wrong solution. The common error that was identified in this solution was the "renaming" of the middle term, $–x$ (i.e. $–4x + 5x$ instead of $–5x + 4x$ or $4x – 5x$). It was further established that solution B was the most misinterpreted one because 115 (43.7%) of the respondents recognised it as a correct solution when it was actually not. This clearly shows that those students did not pay attention to arithmetical computations, neither did they try to confirm whether those solutions could satisfy the given equation or not.

Among the 258 respondents who managed to assess solution C, 191 (74%) made the right choice by recognising it as a wrong solution. This shows that a higher proportion of those students managed to recognise what went wrong in the solution. Although a lot of things went wrong in this solution, about 90% of the respondents identified only one error (i.e. $-3x + 2x = -5x$ instead of $-3x + 2x = -x$). Very few (10%) of them went ahead to look at those errors committed when substituting the values of the constants (a, b, and c) in the quadratic formula $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

All of the 67 (26%) respondents that wrongly identified solution C as being correct indicated that the solution was correct because it was the only one that utilised the correct formula for solving quadratic equations. This group of respondents made such a choice without any attempt of looking at how the formula was utilised. It was also quite surprising to learn that this proportion of students at their level (grade 11) could not even see that $-3x + 2x = -5x$ was wrong. This is a confirmation that some difficulties encountered at primary and junior secondary levels regarding integer addition might have persisted even during their senior secondary education.

DISCUSSION AND IMPLICATIONS OF THE FINDINGS

Considering the nature of mathematical tasks presented to participants, they were expected to provide logical justifications and arguments when explaining the validity of the given conjectures or claims. Although this expectation might sound quite odd since it is not stated whether students had been taught to provide such justifications, it is in line with what the curriculum demands (Curriculum Development Centre, 2013). However, responses from a majority of participants reflect an inadequate view of the nature and function of algebraic reasoning in mathematics (Ontario Ministry of Education, 2013; Van de Walle, Karp, & Bay-Williams, 2011). Students' responses to the given tasks were an indication that most of the work given in their classrooms was more of integer solutions to quadratic equations. Classification of the solutions of quadratic equations based on the value of the discriminant seemed to have been rarely discussed in those classrooms. We concur with other scholars (e.g. Brahier, 2016; Brodie, 2010; Small, 2017) that classroom-based assessment should not be limited to memorisation of facts but to enable students to make conjectures and develop formal or informal arguments declaring or supporting why they believe something is true or false.

Additionally, more than half of the students could not justify why the statement "*$x^2 + 1$ can never be zero for the real x*" is true. We found that most of those who failed to construct valid justifications about the truth of this statement had misconceptions about real numbers. The concept of real numbers is usually discussed in grade 8 (Curriculum Development Centre, 2013) but we found that grade 11 students expressed limited understanding of what constitutes real numbers. Substitution of numerical values into a given algebraic equation also proved to be challenging to most students. Some students refuted the algebraic conjecture because of their failure to square negative numbers. They ended up with not knowing that. This quality landscape also reflects teachers' failure to emphasise the importance of signs when manipulating algebraic expressions and number concepts.

On solution validation, refutation and assessment practices, majority (more than 56%) rightly identified the three given solutions to be (as being) wrong but only 6% of them managed to justify why those solutions were wrong and went ahead to provide their own correct solutions. One inference that can be drawn here is that learners might not have been exposed to such kind of questions. We are of the view that asking students to evaluate and validate suggested solutions of different equations is another way through which teachers could understand students' reasoning abilities and their misconceptions of quadratic equations and algebra in general.

It was also established that some of the student errors and misconceptions were not only due to teachers' 'inappropriate' instructional and assessment approaches. We observed that some students' algebraic reasoning abilities were quite low such that it would be difficult for them to solve algebraic tasks requiring higher order thinking. This is why Greer (2008) suggested that "students should be encouraged to study algebra in the spirit of keeping options open, given its status as a gatekeeper to many educational and economic opportunities" (p.427). In other words, failure to pass algebra in school mathematics should not be encouraged, neither should it be an impediment to a student's educational advancement because some careers may require a great deal of algebra while others may only need some elementary algebra.

CONCLUSION

The main sources of student errors have been attributed to the way teachers teach and the way they assess learners. There is a discrepancy between the demands of the curriculum and the way it is implemented. Teaching to make students pass the examinations has accentuated memorisation and recall of facts among students in most Zambian secondary schools. This demonstrates the need to base teaching and assessment methods on evaluations of how students reason algebraically, and on how they communicate that reasoning to others. To reduce the backwash effect of examinations, teachers ought to discuss with students why quadratic equations are important and how knowledge of algebra or mathematics in general would enable them to solve real world problems. A great deal of research is needed to determine how teachers can ensure that learners are conversant with the functions and characteristics of algebra and how such knowledge could be applied in real life situations.

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MIDDLE-SCHOOLERS PRIMED TO REASON COUNTERFACTUALLY ASK MORE INTERESTING QUESTIONS

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Counterfactual reasoning is a crucial component of scientific inquiry, giving an investigator the ability to design numerous (thought) experiments given a phenomenon. It affords learners the ability to understand complex chain(s) of causal attributions by letting them think about situations where existent factual event(s) are countered in a systematic manner, either by reference to existing data, or by designing new experiments. In this work, we assessed whether asking 5th and 6th grade students (10-11 years old) to reason counterfactually results in a measurable difference in the way they pose questions about a scientific phenomenon - 'biological adaptation'. Our empirical results indicate that the intervention does make a significant difference in the nature of questions asked. Our results have implications for inquiry-based learning, emphasizing the deployment of counterfactual reasoning in science curricula.

INTRODUCTION

Any natural system, be it an organism, an ecosystem, or even an inorganic crystal, arrives at its particular nature through the interaction of multiple factors. Trying to identify how the system would be different if any one factor was changed, *ceteris paribus*, is an excellent way of trying to understand the influence of that factor on the overall system (Minner, Levy & Century, 2002). Thus, the teaching of science offers fertile ground for the application of counterfactual reasoning.

But what exactly is counterfactual reasoning? It is the ability to reason by considering alternatives to the existing fact, or in other words, it is thinking with a 'what if' (Roese, 1997). To illustrate, in an illuminating developmental study, Rafetseder, Cristi-Vargas and Perner (2010) told both adults and 6 year old children a story. A mother could place candy on either the top or the bottom shelf of a cabinet. If she places it on the top shelf, her tall son can reach the candy, but he can't bend down to reach it if it is on the bottom shelf, because he's recently had a fracture and his leg is in a cast. Her small daughter can only reach the candy if it is placed on the bottom shelf but not on the top one. When the researchers asked adults what would happen if the candy was placed on the top shelf and the girl came into the kitchen, they were able to answer correctly 100% of the time. However, only 24% of 6 year olds could answer such counterfactual questions correctly.

This finding exemplifies a view commonly held in developmental psychology, that the ability to reason counterfactually has a significant maturational component and does not arrive at adult levels of competence until about 12 years of age (Rafetseder, Schwitalla & Perner, 2013). However, in contrast, other scientists have discovered the ability to reason counterfactually in children as young as 4 years old (Beck, Robinson, Carroll & Apperly, 2006). It seems reasonable to conclude from the literature, therefore, that a continuum of ability to reason counterfactually exists in children between the ages of 4 and 12 years.

From the educator's point of view, what matters is when the ability to reason counterfactually can be considered *sufficiently* mature to incorporate into classroom praxis as a pedagogical instrument. Given the crucial nature of counterfactual reasoning to scientific inquiry (Kuhn, 1993), this question is of even greater interest to the science educator. In this paper, we make an attempt to introduce counterfactual reasoning into a science classroom at the middle school level and empirically evaluate the consequences.

METHODS

Sample

30 students (14 F, Average age = 10.5 yrs) from an elite English medium private school in Ahmedabad, Gujarat participated in the study. Two groups (A & B) of 15 students (7 from Grade 5, 8 from Grade 6 in Group A, and 8 from Grade 5, 7 from Grade 6 in Group B) were formed. Students were randomly assigned to the groups based on the order of appearance of their names in the attendance register (1st name assigned to A, 2nd to B etc.).

We used the scores of a recent class test in science to determine whether the two samples had varying levels of ability in the subject and/or intelligence differences. Even though the mean score for Group B (16.5/25) was slightly higher than for Group A (15.9/25), a two-sample T-test rejected the hypothesis that the two groups differed in ability ($t_{28} = -0.353$, $p = 0.27$). Thus, at least in a statistical sense, the two samples were ability-matched.

Protocol

The study was conducted on two different days for the two different grades (5 & 6), owing to their separate class schedules. Students from the same grade were divided into two groups (A & B) respectively. The two groups underwent a series of tasks (phases) during the study.

As illustrated in Figure 1, the study had 4 phases in all. Phases I, II & IV were common to both the groups, and are described in detail below. Students in group B underwent an additional Phase III which consisted of a counterfactual reasoning task.

In Phase I, students were shown four physical models (M1, M2, M3 & M4) of plants and animals -2 plants (cactus, water hyacinth), 2 animals (earthworm, rabbit)) to individual students. They were asked to list down the number of structural features (adaptation) that they could observe. In front of each structural feature, they were also asked to write down their understanding of the functional significance of that particular structure. In Phase II, students were provided with information cards on four different ecosystems (marine, alpine, desert and underground- E1, E2, E3 & E4 respectively). Students were asked to perform a match between

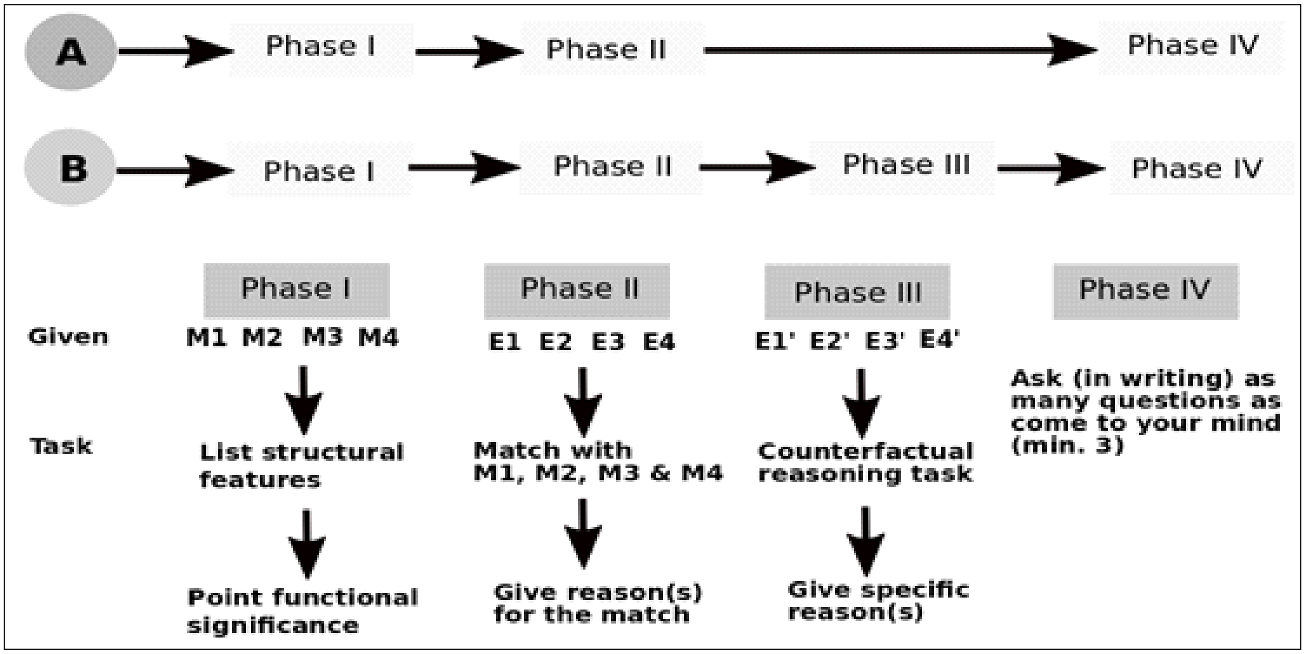

Figure 1: Study Design. See text for details

the model organisms from Phase I and the information cards provided in this phase (II) with minimum 4 reasons for their match.

Phase III consisted of the counterfactual reasoning task, which was undertaken only by Group B students. In this task, students were provided with pictures (but not models) of four new biological organisms alongside a description of the ecosystem they belong to (E1', E2', E3' & E4'), with the set of ecosystems used the same as in Phase II. Students were asked to think about specific structural modifications that would go for each organism that would make it suitable to survive in a different ecosystem. For example, if an organism "a" belongs to ecosystem A, organism 'b' belongs to ecosystem B and organism 'c' belongs to ecosystem C, then students may be asked to think about making structural changes in 'a' to make it survive in B and so on. Students were further asked to give reasons to support their structural modifications.

Phase IV, undertaken by Group A participants right after Phase II and by Group B participants after Phase III, involved a retrospective recapitulation of as many questions as the student could remember (minimum three) occurring to them throughout the activity.

Data

In this work, we present our analysis of questions posed by students in Phase IV of the study. A total of 162 questions were contributed by our 30 student sample across both groups. Interestingly, both the groups posed around same number of questions – 82 questions posed by Group A students and 81 questions by Group B. The entire set of questions were digitized, typographically (but not grammatically) corrected. Sample questions are shown in Table 1.

Group A	Group B
Why does in cactus white things come out?	Why aquatic plant leaves are broad and wax coated?
How did you get this rabbit?	Why does an earthworm have a slippery body?
Why does rabbit have a bushy tail?	What type of eyes do fish have that allow them to see in water?
Why fern look like a Christmas tree?	How do spines grow in cactus?
Why doesn't worms have legs and arm?	How do plants in the last zone of the sea survive with less sunlight?

Table 1: Examples of questions asked by both student groups

Analysis

We analyse our student-generated questions to see if priming with counterfactual reasoning task has had an impact on their quality. We categorize students' questions into multiple groups. This categorization is based upon accepted question-classification protocols reported in education literature (for instance, see Chin & Chia, 2004). We use multiple categorization protocols in order to make meaningful inference about the quality of questions asked to the effect of finding reasonable difference(s) between groups A & B, if any. Below, we report the protocols and the codes we use for categorization:

a) Chin and Chia classification: This categorization is based upon Chin & Chia (2004). We refer to this categorization protocol as the ***CC*** protocol. The categories, codes and corresponding examples from our study are given below:

(1) *Information-gathering question* ***(G)*** which pertain to mainly seeking basic factual information & whose answers are relatively straightforward, viz., 'does water hyacinth only grows in water?' (sic).

(2) *Bridging question* (***B***) that attempt to find connections between two or more concepts. For example, 'why ferns has their leaves in different rows why they can't be like normal leaves?'(sic). Here, the student is trying to link fern leaves with the concept of orientation of leaves of other plants.

(3) *Extension question* ***(E)*** which lead students to explore beyond the scope of the problem resulting in creative invention or application of prior knowledge. For example, 'why cactus store water?' (sic). Here, the student extends her prior knowledge about cactus storing water to know the reason behind it.

(4) *Reflective question* ***(R)*** that are evaluative and critical, and sometimes contribute to decision-making or change of mindsets. We use it to categorize questions which refer to some form of abstraction about a feature or function of the organism. For example, 'how water hyacinth grow in water?' (sic).

Questions that cannot be reasonably coded in any of these categories are coded ***not applicable (N)***. For example, 'why the lab(e)o fish has rhombus design on it?' (sic)

b) Chin and Kayalvizhi classification: This categorization is based upon Chin and Kayalvizhi (2002). We refer to this protocol as the ***CK*** protocol. The categories, codes and corresponding examples from our study are given below:

(1) *Investigable question* **(I),** where questions could potentially be answered by the student by following the scientific method. For example, 'what is inside fern?' (sic).

(2) *Non-investigable question* **(N)**, where questions could either not be answered, or were simply probes for factual information. For example, 'what is the white liquid inside cactus?' (sic).

c**) 5W1H Model:** Finally, a very general semantic categorization of questions - the 5W1H model (for 5 W's: who, what, when, where, why & 1 H for how), traceable all the way to classical antiquity in its provenance - can be applied in any information-gathering setting, including ours. We categorize questions as *why (Y), what (T), where (R), when (N), and how (H)* following the classical protocol, but add an extra category for questions requesting *statements of properties (S)*, e.g. 'is cactus poisonous'?

We also found that at times there were two parts to a question; one was a leading question and the other had either the 5Ws or H posed. In such cases, we coded only for the leading question. To build intuition for the relative strengths and weaknesses of these categorization protocols, we display some sample categorizations in Table 2.

No.	Question	CC	CK	5W1H
1	Why can humans live in almost all places but most animals can live only in certain habitats?	B	I	Y
2	What is the use of long horns in Arabian Oryx ?	E	I	T
3	Why ferns have so short leaves?	R	N	Y
4	Why does frog have blue blood?	E	I	Y
5	Why does the cactus have thorns?	R	I	Y

Table 2: Sample questions from both groups alongside their coded categorizations

Question 1 in Table 2 is coded a *why (Y)* question in the 5W1H protocol because of its semantic intent. It is also coded as an *investigable (I)* question in the CK protocol because the underlying premise can be scientifically investigated, unlike the premise of Question 3, for example, where the premise is a subjective value judgment (N). Question 1 is also coded as a *bridging (B)* question in the CC protocol, since the student appears to be bridging the concepts of survivability and adaptability with the question, unlike say in Question 2, where the student is extending her prior knowledge about the oryx's long horns to understand its purpose (hence coded *extension (E)* question). The code for each protocol for each question was independently coded by two researchers with background in cognitive science & biology education respectively. With an initial 80% match in the coding, the discrepancies were sorted via discussion and a consensus was reached to prepare the final code.

Statistical hypothesis testing of group effects on categorization were conducted using two-sample chi-square tests to quantify the likelihood of whether the categorizations of questions resulting from both groups could stochastically have been sampled from the same underlying discrete distribution.

RESULTS

Our primary hypothesis was that we would find differences in the nature of questions emanating from groups

A and B because of the additional counterfactual reasoning task performed by students in group B but not group A. Below we illustrate the group-level categorizations obtained via each of the three different protocols.

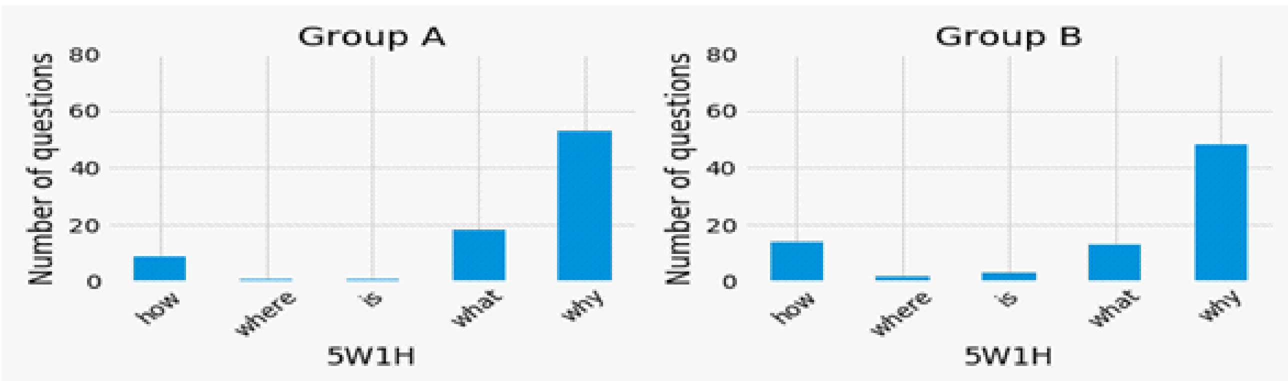

Figure 2: Categorization of students' questions using the 5W1H framework

It is both visually apparent (Figure 2) and supported by chi-square testing (χ^2 = 3.45, p = 0.49) that the semantic categories of questions asked by both student groups are virtually identical. This is a reassuring observation, since it supports the case that any differences found between the two groups will not be a function of language proficiency.

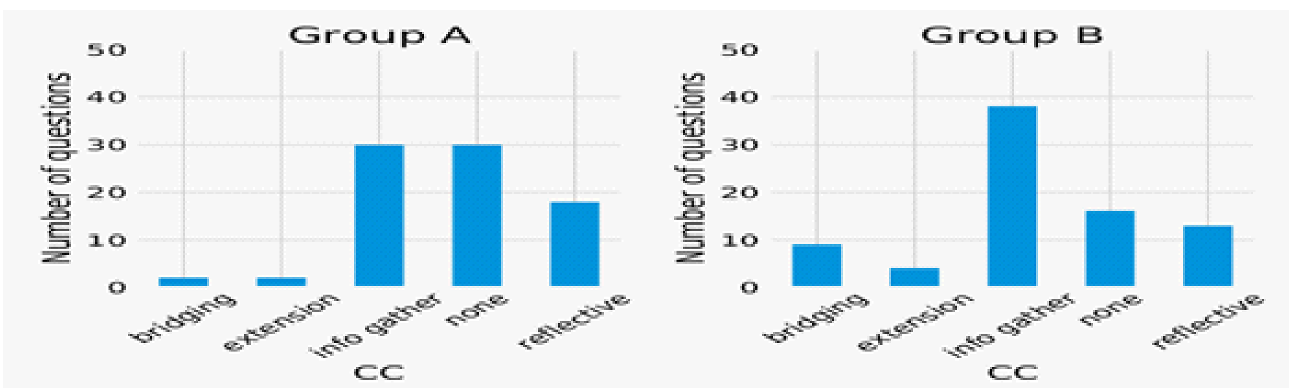

Figure 3: Categorization of students' questions using Chin & Chia's framework

Both visual inspection (Figure 3) and statistical testing (χ^2 = 11.11, p = 0.025) identify significant differences in the question categories seen using Chin & Chia's categorization protocol. In particular, the use of counterfactual reasoning appears to have stimulated the generation of considerably more questions seeking to bridge between concepts (11% of all questions for Group B versus 2.5% of all questions for Group A). Growth is also seen in information-gathering questions, with a corresponding reduction in questions that could not be placed in any category in the CC framework (37% of all question for Group A versus 20% of all questions for Group B).

However, we did not find any significant difference statistically (x^2 = 0.88, p = 0.34) in the CK protocol (Figure 4), perhaps due to the limited number of categories present in this protocol.

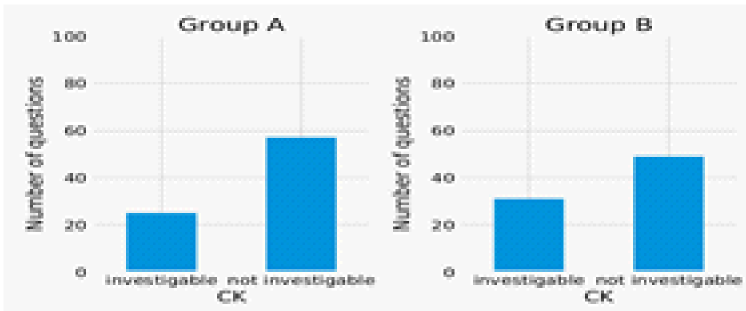

Figure 4: CK protocol Q categorization

The overall gist of our results is that there is a discernible change in the nature of questions being asked by Group B students. The counterfactual reasoning intervention used appears to have stimulated at least some of these students to ask questions seeking to '*bridge*' (see CC protocol) concepts presented in the activity material with other concepts.

Table 3 presents all eight (one question was repeated by two students) unique bridging questions asked by Group B students to bring out the fact that these questions are, in fact, interesting and likely to stimulate deeper understanding of associated concepts. Counterfactual reasoning (italicized) is evident in several of these questions, suggesting that the reasoning task given to the students directly contributed to the change in question pattern.

How can the fish keep its eyes open underwater?	Does the sea lion's nostrils close automatically when they dive into the water?
Why instead of germinating on the dark forest floor, their seeds germinate high up in the mature tree whereas tiny seedlings can get light?	*Why do sea lions propel why do not they have fins just as the fish?*
Generally fishes and aquatic animals have thin skin and less weight, but seal is heavy still is a good swimmer. How?	*Why can humans live in almost all places but most animals can live only in certain habitats?*
Does the pitcher plant have slippery surface so that insect slip inside ?	*Why do Arabian Oryx don't live in Arctic or Boreal region just as rabbit?*

Table 3: Bridging questions asked by Group B students

DISCUSSION

In this paper, we report results from an experiment seeking to identify whether the use of counterfactual reasoning as a learning device for 10-11 year old Indian school children was likely to result in measurable pedagogical benefits. Using a controlled across-subjects design, and a suite of question categorization protocols, we demonstrated a significant effect caused by the use of a counterfactual reasoning activity on the quality of questions asked by students. We also established that the change in quality is not because of semantic changes, but because students become more likely to ask questions that seek to bridge their understanding across multiple concepts.

The empirical study reported in this paper was limited both in scale and scope. Replications of our results for large samples, over longer time-scales, and using more intensive intervention strategies (multiple sessions instead of single ones, bridging multiple concept sets instead of just one set) are clear directions for future work. However, given the paucity of studies on the efficacy of counterfactual reasoning on school students' understanding of scientific concepts, the present work may serve as a stimulant for further activity.

Our results suggest that counterfactual reasoning ability is sufficiently developed in middle school students to integrate activities built around it in science curricula, potentially within the existing ambit of inquiry-based learning (Marx et al., 2004). In doing so, they are in concord with a large array of results from cognitive psychology in the current decade pointing to the sophisticated reasoning capabilities of even very young children that strongly support a strong reconsideration of how curricula and pedagogy for pre- and middle school should be conducted (Gopnik, 2012).

While it is beyond the scope of the present paper to comment on the likelihood of success of this larger ambition, we propose that our more modest ambition of including more inquiry-based learning using counterfactual reasoning in middle school curricula could be fairly evaluated and concretely implemented based on our results and downstream replications planned as future work.

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KNOWLEDGE REPRESENTATION – IN EYE THROUGH EYE WITH BIRDS

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The paper draws from an understanding that every child has an insatiable intellectual curiosity and a touch of imaginative power. Understanding students' views are vital for meaningful learning. The paper reflects on outdoor observations and drawings as an instrument in developing skills, knowledge and appreciation for the natural environment. The paper also reports some interesting findings on knowledge representation through the bird module designed by the author that focuses on a target audience of eighth-grade students. Insights from the study can be directed towards implementing outdoor learning in Indian schools.

REVIEW OF LITERATURE

It is to be agreed upon that, knowledge represented through experience entails learning. Learning influences thinking. Thinking draws a pattern on attitudes from space which may project/reflect through behavior. Affective-behavioural relation of the learner's connect with learning through time has been an important basis for arguing the value of experience. Krishnamurti (1947) observed that every child is born with a natural curiosity. He argues that adults need to encourage children to grow and pursue a variety of subjects by reinforcing their own need to learn. Asserting the role of experience with learning, derived from being immersed in natural settings, Tagore (1917) greatly believed that nature is a child's best teacher. A child's harmonious development will only take place if the child is given unrestricted freedom.

In the Indian context, the Position Paper of the National Focus Group (2006) on '*habitat and learning*' highlights the lack of good quality documentation on some of India's greatest environmental facets and the potentials for building a resource database involving students. The Bird Module provides a framework towards learning through experience, as becoming more meaningful. The module revolves around topics like, the relation of education and experience, learning through experiencing, stimulating learning in outdoor environments, challenges in handling outdoor learning and, linking observational and experiential learning.

OBJECTIVES OF THE BIRD MODULE

(1) Providing an authentic experiential context to learning and scope for developing a behavioural appreciation of the natural environment. (2) Examining evidences that support and engage students in developing transformative knowledge and skills, and ecological sensitivities.

METHODOLOGY

The study followed an exploratory design sought to understand how children relate to their surroundings and reflect on their engagement with learning activities. The study aimed to gather insights and evidence of learning through the process of engagement in different activities like drawing a bird, observing birds from a distance in natural setting and questioning.

The site chosen for the study was an English medium school called St. Johns public school, a CBSE affiliated higher secondary school in Hyderabad. The study was conducted for six days during school hours. Each session was conducted by the researcher for 45 minutes depending on the availability of students. Students from the eighth-grade were the respondents for the study, which mainly involved the age group of 12 to 14 years. This age group marks the cognitive developmental maturation within the child to understand abstract concepts. At this age students are able to comprehend complex ideas and think independently. They develop abilities to identify, observe space and situations around them. Students are also able to reason and question the workings of certain realities and situations. Besides, at this age students are also able to communicate more productively, they are able to articulate, write, read and speak comfortably which is important for their expression of opinions and ideas.

Purposive sampling technique was used in this case. The selected age group was handpicked as the most suitable sample, serving the specific needs for this study (Cohen, Manion & Morrison, 2002). The sample selected represented students from both the rural and urban places, different religious backgrounds and socio-economic settings. Firstly, the outdoor sessions were conducted in the mornings, and the indoor (classroom) sessions were conducted in the afternoons. The school followed two medium of instructions i.e English and Telugu. The sample involved about 60 students, representing gender groups, which consisted of a greater number of girls (37) and fewer number of boys (23). In the outdoor setting students were randomly selected and divided into two groups.

DEVELOPMENT OF TOOLS

Lave & Wenger (1991) state that abstract representations are often related to the power of generality which can be irrelevant unless it is made relevant with a situation at hand. The tools used in conducting the study were designed in a way that could help probe students' ideas, thoughts and views. It was important to understand the way children think and reason. For example; Questioning, drawing, observing, writing, discussing were used as instruments to probe students to think, reason and develop new ideas. In the first two sessions, pictures and videos were used to familiarise and make students aware of the current situation and increase their curiosity.

The pictures used displayed identification of the bird, various state birds in the country, identification of a male and female bird and the habitats of different birds. Each video was presented followed by a discussion on ecology and its relation to different bird species that probed students to ask questions and express their opinions and suggestions on how they relate to the natural environment. (For example, a short documentary on ovenbirds was presented to the class. The video was used to give students a detailed visual representation on how birds build their nests). The video facilitated a discussion on the different types of bird nests and the different habitats that birds belong to. Throughout the sessions, students' doubts and questions were addressed, recorded and noted. Field observations were made by the students during the outdoor sessions. Students were also informed that the data would be collected after each session.

PROCESS OF DEVELOPMENT OF THE MODULE: ANALYSIS AND FINDINGS

The study was organised on the basis of three themes that helped in exploring students ideas and views before and after their engagement with the module. The themes are as follows: 1) Transitions noticed in nature of questions, 2) Exploring thinking through representations, 3) Evidences of conceptual progression. The themes were organised on the basis of commonality that was captured through students' responses. The findings are captured using examples of four cases, R1= Sheryl , R2= John, R3= Fatima and R4= Rahul, which have been analysed at all stages. This is done to help in mapping the shift in the data collected before and after observations.

Transitions in the nature of questions about birds

Questioning is an important tool in exploring student's current knowledge, and also helps in assessing student's understanding by encouraging them to think independently. The theme focuses on exploring the kind of questions and insights shared by students before and after their active engagement with the module. A set of subthemes like, myths and characteristics of the birds were arranged on the basis of the commonalities that were captured through the questions asked by students.

Myths and beliefs elicited in childrens' questioning

It was observed that students were able to express their views and queries freely. It was also interesting to see the difference in the kind of questions asked before the students' engagement in the outdoor setting and after. It was observed that students began to ask more specific questions after the outdoor activity. For instance, if we look at Sheryls (R1) nature of questioning before the engagement in table 1.1, she focuses more on understanding and finding answers to questions based on stories that she probably must have read or heard previously. Her question was a very interesting one as this example showed how students partly believe what they see or hear, but are also very curious in addressing the reason behind why certain things happen the way they do. The questions also highlight students curiosity to know the reasoning attached to a myth.

Notable changes could be seen through students questions after their engagement with the environment. Evidently, the questions also highlight the nature of details students attended to, when engaged in outdoor observations.

Students were more interested in understanding specific details and features of the bird, as illustrated in table 1.1. For example, R1 wanted to know how birds communicate, she was especially interested in knowing how woodpeckers communicate or how she could identify the sex of the bird or know when the bird is a male

Themes based on commonalities	Questions asked **before engagement**	Questions asked **after engagement**
1) Myths 2) Features of the bird 3) Food and habitat 4) Gender reproduction	**(R1)** Sheryl	
	1) *Is it true that if we touch a small or a big bird. the birds family will not be able to recognise it and they will kill the bird?* 2) *Is it true that if we kill a bird or her babies the family will take revenge?*	1) *How can woodpeckers communicate?* *2) How can birds drink water?* *3) How eagles can fly without swinging their wings?* *4) Why a hen cannot fly too high?* *5) Why can't other birds fly without swinging their wings?*
	(R2) John	
	My grandmother says, souls of the dead enter into the crows body and the crow will have to be fed for the dead soul. is it true?	1) *Why is the Indian paradise flycatcher called the bird of paradise?* *2) How reproduction occurs in birds?*
	(R3) Fatima	
	Do birds also get headaches or stomach pain just like humans do?	*What are the kinds of materials birds use to make their nests?*
	(R4) Rahul	
	Why birds move their tail when sitting on a branch of a tree?	How can a bird be identified or known which bird it is once it has been spotted?

Table 1: Shift in the nature of questions elicited from students questioning

or female. Similarly R3, the questions she asked before the engagement showed her interest and curiosity in understanding the world around her. For example, R3 wanted to know if birds get stomach aches and headaches, thus indicating that she was able to think and frame questions based on abstract ideas even before engaging with the activity. There seemed to be an evident shift in the kind of questions R3 asked after her engagement with the natural environment. She now wanted to know about the kinds of materials birds use to make their nests. This could be attributed to her observations and her attention skills to understand the detailing of the way nests are built and the kind of materials that support them. R2's question after his engagement with the environment was quite different from before. He was more curious in knowing more specific details on birds, for example; "how reproduction occurs in birds".

Exploring thinking through representations

Students use drawings to express their ideas of how they represent the world around them. Interestingly, it was observed that students created evident differences in their representations of birds before and after their outdoor engagement. The meaning drawn from the representations created by students also suggested the use of visual and conceptual analogies. Forbus, Usher & Tomai (2005) describe analogy as a powerful learning mechanism that captures the breadth of cognitive processing. During the second session, students were asked to draw/ sketch a bird through their understanding, experiences, knowledge of a bird with no further instructions on what should be highlighted or how the labelling should be done.

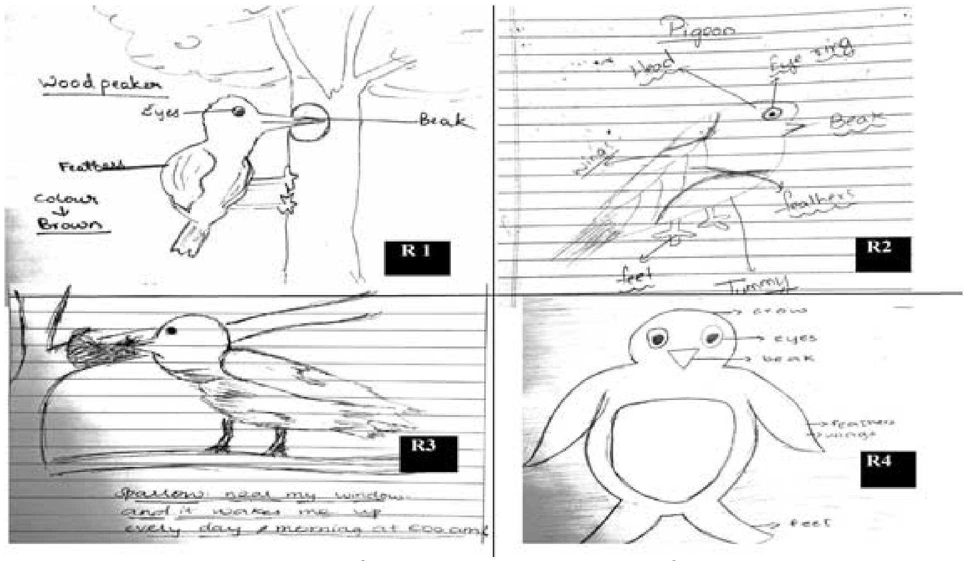

Figure 1: Examples of sketches made by students before engagement

Figure 1 depicts a few examples of the drawings made by students before their engagement with the environment. The sketch created by R1 suggests how the student was trying to connect the idea of bird in the context of doing something. For example; the sketch depicts an image of the woodpeckers pecking behavior. It can be noted that the students categorizing in this case is based on the activity that the bird is engaged in. This case is also a classic example of students trying to attach and depict a specific activity that a bird is usually associated with. The sketch created by R2 suggests that the child has culminated features from different species into creating the image of the bird. For example; in Figure 1 it is inferred that the student has created an image of a pigeon by using characteristics that are almost similar to fish scales or a leaf.

The second inference made here was that the student attempted to draw a visual equivalent to understand that the bird is camouflaged due to the presence of leaves around it. R2 seems to have focused on enhancing features like, the wings of the bird, the beak and its feet. R2 also highlighted the stomach of the bird which suggests the student is trying to connect the prominent features of a human body to a bird.

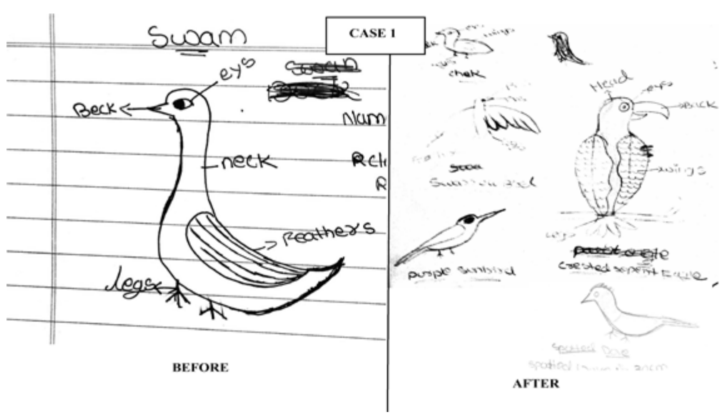

Figure 2: (Case 1) Drawings made before and after observations

Figure 2, case 1 displays the drawings made by Sheryl. There was an evident shift in her drawings from before and after the engagement where her observations showed up in her drawings. Some change was also observed in the way she has highlighted specific features of the bird after observations. A striking evidence was seen in the shift of the diversity of bird species included in her drawings from nature. She also seemed to have conceptualized the idea of size by portraying the relative size variations of the birds. She also described her observation by the colour and the size of the bird, the number of birds of the same species she sighted and the time at which she saw the birds. She also commented, “I did not know the name of the bird, it was jumping from one branch to another, the second bird I observed was also an unfamiliar one”.

Evidences suggesting a shift in students representation of bird species after engagement

This study was an attempt to understand the difference in students’ views about bird species (represented in drawings) before and after the outdoor observation-based activities.

Before observations (Day 1)		**After observations (Day 3)**	
Name of the bird	Number of students	Name of the bird	Number of students
Sparrow	12	Paradise Flycatcher	14
Peacock	9	Indian Robin	5
Pigeon	6	Spotted Dove	8
Parrot	4	Red Whiskered Bulbul	4
Crow	4	Drongo	4
Other birds’ category enumerated: Hen: 3 Kingfisher: 3 Puff throated bulbul: 1, Weaver bird:1, Humming bird:2 , Ostrich:1			

Table 2: Evidences suggesting a shift in students representation of bird species

One of the major findings in the study was the shift in students’ representations of the bird species. Table 2 shows a significant increase in the number of birds and the diversity of species observed and represented by students after their engagement with the module. During the initial stages that did not involve any observations, students represented species that were most commonly seen. These included familiar bird species such as Sparrows which were sketched by 12 students, pigeons as sketched by 6 students, Peacocks by 9 students ,Crows and Parrots by 4 students respectively. Whereas the observed species after the engagement included a more diverse array of birds which students were previously unaware about. These birds included the Paradise Flycatcher, Spotted Dove, Indian Robin, Red whiskered Bulbul and Drongo. In Table 2, “The other birds category enumerated” suggests the constancy in the names and sketches of birds represented and the number of students who sketched the birds.

Another interesting reflection was the change in the use of language by the students to describe the birds. The terminology shifted from the usage of generic terms like black birds, blue parrot and attributive adjectives like the elegant crow, colourful peacock, queen bulbul to more specific and accurate bird names for example, Spotted Dove and the Paradise Flycatcher.

CONCLUSION AND IMPLICATIONS

The thrust of the paper is to facilitate a child's connection to knowledge, through transformative experiences –- to provide a sense of Progression. One of the major inferences made through the outdoor engagement was the transitions in the nature of questions asked by students. The finding reflects back on the principles laid down in the National Curriculum Framework, NCERT (2005) document which explains how students can import the acquired skills from their outdoor learning to classrooms. The paper also emphasizes the importance of asking questions to help enrich the curriculum.

The insights from the study helped understand students perception about birds before and after their engagement with the natural environment. The evidences emerged through the study highlight the need for exploring the conceptual and theoretical aspects of outdoor learning. The study raises numerous avenues for future investigations to deepen our understanding of incorporating outdoor learning into classrooms.

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EXPLORING MATHEMATICAL EXPLORATIONS

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A Mathematical Exploration is a loosely defined problem situation that has the potential to generate multiple questions, at least some of which allow for further questioning that lead to mathematically significant results, through means that are mathematical. For most students, such explorations offer a new and friendly perspective of mathematics and it is important to provide them with such educational opportunities. What does it take to enable and sustain mathematical exploration in a classroom? Based on the experience of taking four different cohorts through an exploration, this paper addresses this question and provides some preliminary answers. The larger study, of which this paper is a preliminary step, hopes to understand the exploratory process better so as to be able to come up with a 'local instruction theory' for explorations.

INTRODUCTION

Skovsmose (2001), in his essay Landscapes of Investigation, differentiates two different learning milieus. According to him, traditional mathematics education falls within what he calls the exercise paradigm, where a mathematics lesson is occupied with two kinds of activities–a teacher presenting some mathematical ideas and techniques and students working on some related exercises. The relative proportion of time occupied by these activities may vary, but the activities themselves don't. He contrasts this with 'Landscapes of Investigation', which invite students to formulate questions and look for explanations, rather than solve the exercises set by the teacher or the textbook and is characterised by classroom practices that support an investigatory approach. "When the students in this way take over the process of exploration and explanation, the landscape of investigation comes to constitute a new learning milieu." (Skovsmose, 2001, pp.125)

In the Indian context as well, we see this dichotomy with the policy documents envisaging the latter paradigm and the former prevailing in classrooms. The National Focus Group (NFG) Position Paper on Teaching of Mathematics talks of the need to ensure learning environments which invite participation, engage children in posing and solving meaningful problems, offering them a sense of success and to "liberate school mathematics from the tyranny of the one right answer found by applying the one algorithm taught", through a multiplicity of approaches, procedures and solutions (NFG, 2006).

Polya (1945) talks about the need to challenge the curiosity of students by setting them problems appropriate for their mathematical knowledge and helping them solve the problem with stimulating questions, thus giving them a "taste for and some means of independent thinking". Without this a student may miss out on the opportunity to know whether he/she has a taste for mathematics at all. We see mathematical explorations as a means to provide such an opportunity.

'Mathematical Exploration' is an open-ended and loosely-defined problem situation, that involves students asking their own questions, choosing the ones that interest them, following different paths to find answers and asking further questions.

The Oxford dictionary defines exploration to be "The action of travelling to or around an uncharted or unknown area for the purposes of discovery and gathering information; the action or activity of going to or around an unfamiliar place in order to learn about it; expedition for the purpose of discovery'' (OED Online, 2019). This is a relevant image for mathematical explorations by students as well. Critical to exploration is the unfamiliarity of the terrain. It might have been charted extensively by others, but the fact that it is new terrain for the student is important. Navigating the terrain for the purposes of discovery and gathering information is both challenging and engaging for the students. It is here that the availability of reliable maps, and a tour guide can make a big difference. It is also clear that the terrain may be difficult but not forbiddingly so, lest the explorer give up too early. Existence of vantage points from which one can take an overall perspective of the route travelled and pathways ahead greatly helps the exploration.

Similarly, an activity that is intended to set forth a mathematical exploration should be unfamiliar enough so as not to have a learnt solution and at the same time relevant, engaging and approachable. The entry point to the activity should be accessible to every student and ideally there should be multiple entry points. At the same time, the activity should have the potential to challenge the more interested students and keep them involved. In other words, the activity should have a 'low threshold, but high ceiling' (LTHC). The activity should have the potential to branch out into multiple trajectories, at least some of which have the potential to raise deeper questions, which the students have the necessary resources to solve. These solutions themselves could generate further questions, some of which may not be as yet answered by the general mathematical community. A Mathematical Exploration provides opportunities to raise questions, the answers to which are hitherto unknown to the explorer and sometimes even to the community at large and find answers by engaging in the processes of mathematics.

In taking over the process of exploration and explanation, students are functioning like 'little mathematicians', posing questions that interest them, and engaging with the processes of the discipline like coming up with conjectures, visualising, representing, estimating, justifying, generalising, and overall experiencing the joy of making their own discoveries. This gives them a different kind of experience of doing mathematics , different from the fearsome and anxiety-inducing one that they are used to (Ramanujam, 2010). In the learning milieu created by explorations, every child has an opportunity to succeed at some level. In the Indian context, one of the first attempts at creating such a learning milieu can be seen in Eklavya's Prashika Project, though at the primary level (Agnihotri, Khanna, & Shukla, 1994).

RELATED RESEARCH AND ENSUING QUESTIONS

Problem posing and solving and engaging in the processes of mathematics or 'thinking mathematically' are three key aspects of a Mathematical Exploration. Understanding what is involved to enable and sustain an exploration in the classroom calls for taking a closer look at each of these three aspects and how they come together in an exploration. In addition, one also needs to understand the role of the students, teachers and the material in the process. We present a brief overview of research on these aspects.

While there has been considerable research on Problem Solving and multiple aspects of it, (Polya, 1945; Törner, Schoenfeld, & Reiss, 2007), problem posing has garnered attention in recent years as well (Brown & Walter, 2005; Singer, Ellerton, & Cai, 2015). In their seminal work on Mathematical Thinking, Mason, Burton, & Stacey, (1982) delineate the practices involved in thinking mathematically and identify specialising and generalising, conjecturing and convincing, imagining and expressing, extending and restricting, classifying and characterising as the core mathematical processes. Others (Bell, 1976; Watson, 2008; Schoenfeld, 1985) have slightly different characteristics of the processes involved.

There has also been a closer look at these disciplinary practices and characterisation of progression in mathematical thinking. Zandieh and Rasmussen (2010) and Rasmussen, Zandieh, King, and Teppo (2005) exemplify how students in undergraduate classrooms engage in disciplinary practices like defining and symbolising. These papers evolve a framework to describe the stages in their progression.

A natural question arises as to whether a similar framework can be created for secondary school students, characterising the progression of thinking and the development of disciplinary practices during explorations. Some spadework in this direction can be seen in Cai and Cifarelli, (2005) and Cifarelli and Cai, (2005). Through a case study of two college students the authors examine how an interplay of sense-making, problem-posing and problem solving sustains an exploration and initiate the development of conceptual frameworks and research tools to capture mathematical exploration processes. They identify two levels of reasoning strategies in the process– hypothesis driven and data driven. However these are not sufficient to develop a 'local instructional theory' (Gravemeijer, 2004) for mathematical explorations that describe potential learning trajectories through which students might progress, thus functioning as road maps or frames of reference for teachers who want to engage their students in an exploratory activity.

We note that the idea of a 'local instructional theory' is closest in spirit to this work. While such a theory has been developed in a specific content area, and for processes such as definition and symbolisation in the content area, our eventual goal is to develop a similar theory for explorations at the secondary school. However, while theorisation is the principal aim of this line of research, the account presented here is too preliminary for any theory-building as yet.

Jaworski's work on the role of the teacher in an Investigatory classroom, (Jaworski, 1994) identifies some generic pointers like sensitivity to students and need for mathematical challenge to sustain an investigation, but does not answer questions like - What moves on the part of the teacher help or hinder an exploration? At what stage in the progress of an exploration is an explicit hint helpful and at what stage is it a better choice to let the students struggle to find their own path? What is the nature of preparation that a teacher should have before starting on an exploration with students? These and related questions on other enabling/hindering factors for an exploration form the backdrop of this study.

STARTING POINT AND POTENTIAL TRAJECTORIES

Combinatorics offer many rich possibilities for explorations (Maher, Powell & Uptegrove, 2011). The 'starting point' being considered for this paper is a puzzle where students are invited to arrange numbers 1-6, using each exactly once, in circles arranged along the sides of an equilateral triangle, in such a way that the sum of numbers along the three sides are equal (Trotter, 1972). That there are four such distinct arrangements provides an access point to all students into the task since they can discover these by mere enumeration and sets the ball rolling with questions such as What does it mean to say distinct solutions?, How many distinct side-sums are possible? What are the upper and lower-bounds for the side-sums?, Are these the only solutions? How does one prove that there are exactly 4 solutions? What patterns can be seen in the solutions? How can one 'transform' one solution into another? How many solutions (non-distinct) can be obtained by rearranging one given solution? How is the side sum related to the corner sum (which is the sum of the three numbers placed at the vertices of the triangle)? Can the side sum ever be twice the corner sum?

While staying with an equilateral triangle formed with 6 circles, one can ask further questions like – what if a different set of numbers are used instead of 1 – 6? Do the numbers have to be consecutive in order for solutions to exist? Will there be 4 distinct solutions, whatever the choice of numbers? If not what condition should the numbers satisfy for the existence of 4 distinct solutions? What conditions should the numbers satisfy for the existence of a solution at all?

The more interested students can engage with questions like – What if the circles are arranged in the form of a square? Or a pentagon or any other polygon for that matter (Trotter, 1974)? What if there are more than 3 circles per side? What if the circles are arranged in the form of an open curve like an S or a Z? Which of the questions asked in the context of the initial triangle are still relevant? Can the solutions/methods of solutions used there be generalised to these arrangements?

Thus we see that the 'task' meets the LTHC criteria, generates multiple questions and divergent paths for exploration. Starting from a simple puzzle also ensures the engagement of all students. It also touches upon some significant mathematical ideas like the existence of upper and lower bounds, proofs of existence or non-existence of solutions, generalisable methods that work across a range of problems etc. Students also get opportunities to engage in the processes of mathematics like observing patterns, coming up with conjectures, looking for examples or counterexamples, justifying, generalising etc. This task was tried out with multiple groups of students and similarities and differences in the way it panned out observed.

THE STUDY GROUPS

The groups differed widely in terms of the prior exposure that they had to mathematics. Some details of the different groups are as follows:
Cohort A: about 10 students from grades 8 and 9 of a corporation school

Cohort B: about 10 students from grades 8 and 9 of a low-fee private school with students from disadvantaged socio-economic backgrounds

Cohorts C and D: about 25 students each who were part of a talent nurture camp in mathematics and from fairly affluent backgrounds

In terms of 'mathematical background' cohorts A and B can be considered similar, and C and D are similar as well. Cohorts A and B were drawn from 'typical' schools whereas cohorts C and D had been identified as potentially 'talented' in mathematics and had been through focused enrichment programs for a few days every year for the past 4 years. While it is interesting and important to study the impact of socio-economic context on mathematical explorations in the classroom, this paper does not take up this difficult comparative task and contents itself with the more basic question of whether explorations take place at all, across these contexts, and how they proceed. All four groups spent about 2- 3 hours on the task. This account is based on reflective notes of sessions and audio-recordings of sessions with cohorts A and B.

THE OBSERVATIONS

The way the exploration progressed with each of these four cohorts was distinctive, even though there were pairs of cohorts with similar mathematical backgrounds. While some questions and conjectures came up uniformly across all groups, the arguments that each group came up with in support of these were different. In this section, we highlight some of these similarities and differences.

Finding distinct solutions phase

The four distinct solutions were found out by all four cohorts, some sooner and others a little later. Different approaches to finding the solutions were seen. Though all of them started off with a trial and error method they evolved differently.

With cohort A, fairly early in the trial and error phase, after three solutions were found out, the question "Will all the numbers come as sum?" was raised by a student. The teacher, noting the potential of this question to go beyond finding solutions phase, revoiced it to the whole class. Possibly guided by this prompt, possibly not, one dominant method of looking for solutions that was seen in this group was to try to find an arrangement with a pre-determined side-sum.

Some students from cohort B engaged in a similar kind of reasoning as well, but here a student realised very early on that moving around the numbers in a given solution in a cyclic order yields another solution. Having found this, the group looked for other transformations that could be done to get more solutions from ones already found out. So for this group transforming existing solutions came to become a standard strategy to look for more solutions even when working with numbers 1-6.

Using transformations of existing solutions to generate newer solutions happened with cohort A as well, a little later, but with much excitement. The student who first thought of it claimed 'ownership' to the findings by calling them ‘N’s theorem I’ and ‘N’s theorem II’ on his own, and the whole group toed the line, adopting the same terminology for the rules! They also reached the conclusion that if they find one solution another one comes free by applying the ‘theorem’ and found out some pairings happening among the solutions. With cohorts C and D the four distinct solutions came up within the first few minutes. Though the solutions came up from different individuals, the four solutions were recorded on the blackboard very soon. The patterns among the solutions and using them to find further solutions did not emerge as points of discussion. However, these groups also had some systematic way in which they generated solutions. Cohort C for example came up with the strategy of fixing the corner numbers, and putting in the minimum of the remaining three numbers in the centre of that side where there is a maximum sum of the two numbers at the corners, and so on.

Thus, examining the different ways in which the finding four distinct solutions to the triangle puzzle panned out with four different cohorts, we notice the following:

- All 4 groups moved from looking for solutions through trial and error to better mathematical ways, though along different paths and at different rates.
- The kind of prompts given by the teacher, or the kind of student findings/conjectures chosen to highlight or revoice to the whole group may have influenced the path the exploration took.
- The sense of joy the students had in finding out something for themselves, the sense of ownership they had for these findings and how they built on these findings was evident in all four groups.

Finding the upper and lower bounds for the side-sum

The attempt to find ‘yet another solution’ to the puzzle soon led all the groups to the conclusion that some side-sums are possible and some are not. Soon all four groups came to the conclusion that side-sums below 9 above 12 are not possible. But they had different ways of arguing this.

For cohort A the initiation to think along these lines came from the question – “will all numbers come as sums?” The first response was that numbers 1-6 have to be ruled out. Soon numbers 7 and 8 also got added to the ‘not-possible’ lists. One of the first ‘arguments’ that came up went something like ‘3, 4 and 1 add up to 8. Now we have to have 6 somewhere and there the sum will go up. We can have a sum of 8 only on one side.” which eventually M refined to “In some circle we have to have 6. Smallest number is 1. On a side there are two more circles. To get 8 there we need to add two 1s (to the 6) and we can’t do that.” However, they did not come up with a similar argument as to why a side-sum of 13 was not possible, in spite of the teacher prompting them to follow a similar reasoning.

Cohort B also followed a similar path, trying out specific combinations of numbers and realising that they would not work and then coming up with an argument for 8 being the lower bound. Like cohort A they did not extend it to the upper bound.

Cohort C and D on the other hand did not give the specific case based arguments, but straight away gave the argument similar to that which M of cohort A had come up with to establish side-sums of 8 or less are not possible and extended it to argue that side-sums of 13 or more are not possible as well. Choosing that side of the triangle where 1 occurs, the maximum possible sum is got when the largest of the six available numbers namely 5 and 6, are on the same side, giving a sum of 12.

Later on in the course of the exploration, student N from cohort A, mentioned in an earlier paragraph, figured out a way of finding out the max sum and the min sum for any given set of numbers. He found out that the max sum was obtained when the larger three numbers occupied the corners and the min-sum when the smaller three of the six numbers were at the corners. He also saw that the smallest of the remaining three should be put in the centre of that side where the larger two numbers are at the corners and vice-versa to equalise the side-sums. Though N didn't explicitly make the connection, this results in expressions for the min sum and max sum given any set of six consecutive numbers.

Here we see that, through exploring possible and impossible side-sums, all 4 cohorts were coming to the important mathematical idea of looking for lower and upper bounds for the side-sum. But the kind of arguments that they come up with show different levels of mathematical thinking. We have students –

- trying out specific cases and concluding from them that certain sums are not possible (without a proper justification),
- coming up with a justification for the impossibility of specific side sums (say 8 and 13) and in principle, extending the same argument for smaller and greater numbers as well,
- coming up with a general expression (well, almost!) for the max and min sums in terms of the given six numbers.

Proving that only 4 solutions exist

This could have been done on multiple ways –

1. by exhaustively considering possibilities,
2. by using parity arguments,
3. having proved that there are only 4 possible side sums, by proving that each of these corresponds to a unique solution,
4. using algebra to establish a correspondence between possible side-sums and corner sums and use this to limit possibilities.

None of the 4 cohorts started on any of these on their own accord. Knowing that method 4 above is extendable to the variations of the problem discussed in an earlier section, the teacher explicitly cued this method, by suggesting that they 'let a,b,c,d,e,f be the numbers 1 to 6 in some order and S be the side-sum' and asking them to write an expression for the sum of numbers on each side in terms of S and a,b,c,d,e,f. With varying degrees of teacher support, cohort B, C and D came up with the relation that

$$3S=\sum_{1}^{6} n + C,$$

where C is the corner sum. All three cohorts inferred that the corner sum has to be a multiple of 3 and used this to limit the possibilities to arrive at a proof. Cohorts B and C explored the generalisability of this method to other alignments of circles as well. This exercise could not be taken to completion with cohort A for want of time.

Here we see the crucial role of the teacher in keeping the exploration going. There are times when the teacher has to make an explicit suggestion instead of waiting passively for students to come up with those critical insights. In this case, with cohort A, the teacher waited unduly long, giving indirect hints to students which they did not catch on. Consequently there was loss of time and the exploration did not progress as much as it did with the other cohorts. The sense of not being able to progress resulted in feelings of frustration in students and their enthusiasm to engage with the exploration waned. Having learnt from the frustration of students and from discussion with others, the teacher changed strategy and made some explicit suggestions in subsequent trials of the module. Thus, it is a hard task for the teacher to balance between giving just enough support so that students stay motivated and at the same time leave sufficient opportunities for them to struggle and discover things for themselves.

CONCLUDING REMARKS

Each of the subsections of the previous section describe three 'instances' in the span of an exploration, each drawing attention to a different aspect that needs closer scrutiny. In the first subsection we describe the movement of all 4 cohorts from trial and error methods to more mathematical ways of solving. This raises the question: what cues (from peers, teachers or materials including tasks themselves) support or hinder this move? The description in the second subsection highlights the different levels of mathematical thinking seen, calling for a clearer description and characterisation of these levels and possible learning trajectories through these levels leading to 'a local instructional theory' of mathematical explorations. The third subsection highlights an instance where a teacher move or lack of it hinders an exploration calling attention to the scaffolding needed and to the timing of provided support.

Even with these limited instances, we can see some essential characteristics of explorations: realisation that there are many solutions leads to the 'how many' questions, and then to the 'how does one know if there are no more' question. Extensions and generalizations occur naturally. The difficulty is also clear: when and why does an exploration stop, or run out of steam? What learning can one carry from one exploration to another? These seem to merit a deeper investigation, and will hopefully contribute to the theorization we seek.

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ELICITING ARGUMENTATIVE REASONING AMONG SECONDARY SCHOOL CHILDREN USING SCENARIOS AND COUNTER-EVIDENCES ON SOCIAL ISSUES

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This study locates reasoning and argumentation within the domains of developmental psychology and curricular interventions. It then investigates patterns in arguments generated by children when faced with conflicting social scenarios. To this end, 12 students from two schools were interviewed via the Clinical Interview method. The findings that emerge from the analysis of their responses demonstrate children's tendency to argue by means of reasoning aligned with their prior knowledge and personal experience, and hold relevance for research in judgement of knowledge claims for meaning making. They also indicate that the position of authority may play an important role in elicitation of their arguments. Finally, the study outlines areas in the domain of reasoning and argumentation that exist in the scope for further research.

INTRODUCTION

One makes sense of their environment by means of the knowledge, skills and value sets they already possess and that are passed socially to them by means of education. Reasoning facilitates this assimilation, a process which is today understood to be indispensable in the process of defining curriculum for the generations to come (National Council of Educational Research and Training, 2006). This is where the skill of reasoning becomes significant to effect social transformation by enabling students to analyze their experiences and their learnings from those experiences. In this vein, the learner must be enabled to reason their immediate existence in the society as product and the inspiration of the disciplinary knowledge that is presented to them. Unfortunately, this enabling is yet to find representation in the way we reproduce knowledge in education. As an example of the disconnect that may exist in our education, one may consider the history of the anti-caste movement in India and the depiction of this movement within the school curriculum (Kumar, 1983; Vishwanath, 2012). One thus observes a pressing need to provide our educators and teachers with the tool of questioning and reasoning in order to effectively translate content into constructive learning.

LITERATURE REVIEW

The discourse on reasoning amongst children today emerges out of the field of developmental psychology and builds itself against a strong reference to Piaget's work on systematic development of the cognitive processes of the child. Through his interactions with children, Piaget (1958) examined learning in children in terms of how they isolate and integrate variables in the environment.

In light of understanding environmental factors influencing reasoning, children's interaction with the 'other' in the form of peers, teachers and other adults have been studied as well. Shafto, Eaves, Navarro and Perfors' (2012) study attempts to model young children's reasoning about the knowledge and intent of the informants by analyzing their biases via a computational model of epistemic trust. Figures of authority play an important role in the practice of reasoning in children, for although they are found to not be naturally oriented towards obedience, they do understand social and institutional relevance of authority (Laupa, 1991) and their reasoning can be significantly influenced by teachers' expectation of "reasoned actions and responses" and authentic opportunities of reasoning (Diezmann, Watters & English, 2002). A deeper probe into children's reasoning through their responses to conflicting scenarios thus surfaces. With implications especially for the field of science education, these studies employ methodologies of semi-structured interviews with open ended questions and conduct conversational analyses on the "informal reasoning" employed by children in evaluation of complex socio-scientific issues via argumentation (Sadler, 2004). More studies in the contemporary research in reasoning today deem argumentation as a feasible gateway into uncovering the processes of reasoning amongst children (Kuhn, 1991). Kuhn's subsequent work (Kuhn, Cheney & Weinstock, 2000) unpacks this reasoning to reveal different levels at which personal epistemologies of children may operate (abolutist, multiplist and evaluativist) as 'knowing' of the child moves from objective dimensions to subjective ones. Fischer, et al. (2014) in their review of latest developments in the field of scientific reasoning and argumentation cite studies that depict students exhibiting "poor dialogic or social quality of argumentation as reflected in the social exchange and co-construction of arguments". However, there have been multiple techniques and models employed within classrooms that demonstrate positive results with regards to learning (Choppin, 2007; Elbers & Streefland, 2000; Forman, Larreamendy-Joerns, Stein, & Brown, 1999; Stylianou & Blanton, 2011).

In the Indian context, although the media, literature and academia are ripe with discursive conflicts as a result of a chaotic co-existence of cultures, the educational institution is one space, of many, wherein classroom spaces have been observed and reported to be didactic in nature, with little opportunities for alternative subjective expression by the students. (Educational Initiatives and Wipro, 2006; Smith, Hardman, & Tooley, 2005). Therefore, there is scope for exploration of reasoning and argumentation as it exists within the dialogic paradigm of children, with important implications for its application in the classroom scenario in the future.

OBJECTIVE

This study aimed to:

1. Develop appropriate case scenarios (along with resource cues that constitute counter-claims) that are contemporary, familiar and present conflicting perspectives on issues of social concern.
2. Invite students to take a stance on the case through a process of reflection and reasoning by posing challenging counter-arguments.
3. Examine the patterns of argumentation emerging from the interactions with case scenarios.

METHODOLOGY

The study employs an exploratory framework in investigation of the nature of argumentation in children. It is set in two schools in Rajendranagar, Hyderabad. The first school is a government school and the second one a budget private school. The schools were chosen as per convenience as the study did not necessitate a case-specific or theme-specific criteria for the schools. Employing convenience sampling in the study, a sample of 12 students (6 boys and 6 girls) from eighth grade from the two schools was taken. The interaction took place in English.

It was necessary that the subject of conversation stimulate intensive expression of the child's opinions, and thus, have scope for taking a stance. Three topics holding such a scope were finalized based on the criteria of: familiarity of the child with the subject, relevance of the subject and scope for development of original arguments. The first topic related to vegetarianism versus non-vegetarianism, the second concerned whether video games are good or bad for players, and the third was the increase in establishments of supermarkets and whether it is good or should local markets be preferred. For each of the topics, a repository of anticipated reasoning of participants for their opinions was created and counter arguments justified by information endorsed by various authorities were developed. These authorities were: religious leaders, religious texts, news outlets, health websites, survey results, researchers and scientists, celebrity figures, a philosopher, a journalist, authors and a policy head. These figures represent multiple knowledges and multiple ways of knowing as extant in society, and thus there was an attempt to refrain from depicting a hierarchical legitimization of any one form of knowing. This was done to enable expression of the participants' personal opinions freely. Statements and findings by these knowledge authorities were printed on to placards categorized into two sets for each topic. Each topic, then, had two sets of placards wherein one presented arguments 'for' the topic and the other 'against'. These sets then comprised the tool that was used in the one-on-one interviews conducted with the participants.

It was important for the interviews to be guided by the response of the participant as the objective of the study seeks to elicit their unrestrained opinion. The planned questions were to be kept at a minimum and open ended, and further questioning would be for the purpose of encouraging elaboration or offering a counter argument in order to allow the participant's reasoning to surface. The study, thus, attempts an application of the Clinical Interview method (Ginsberg, 1997). The administration of the interviews with the participants happened with the aid of the informational placards as described earlier. Each interview had three sections corresponding to the three topics concerned, in the order:

1. Vegetarianism vs. Non-vegetarianism (T1)
2. Video games (T2)
3. Supermarkets vs. Local Markets (T3)

Each section commenced with the participants being asked one of the following questions as per the topic:

1. (a) Are you a vegetarian or a non-vegetarian?
   (b) Do you think being a vegetarian is better or is it better to be a non-vegetarian?
2. Do you think video games are good for us or bad for us?
3. Do you think it is better to have supermarkets or local markets?

Once the participant responded with the reasoning behind their opinion, they were offered a counter-argument prepared on the placard. The pieces of information that were offered were either in direct contestation to their response, or implied the same. The interactions thus made were recorded via the sound recording application on the researcher's mobile phone and transcribed for analysis.

ANALYSIS AND FINDINGS

An analysis of the data, identifying certain characteristics of the participants' responses is presented below. There is an attempt to shed light on their efforts to respond to a counter to their rationales, as they source that attempt from their personal beliefs (or as it may appear, epistemologies).

Table 1 depicts the number of counter-cues that were offered to the participants leading to either a complete change in the expressed stance of the participant ('Y'), no expressed shift in stance ('N') and a state of indecisiveness for a shift ('U'). Instances where the participant would express that they concede after continued countering of their reasons for their stances with information cues have been noted as Y. If their responses clearly showed that they were unyielding to the counter cues, they are noted as N. There were instances where ambiguity was observed in terms of the participants' shift in their stances. These are noted as 'U?' and depict a lack of any more reasons from the participant to justify their stance.

We can observe an increase in the average number of counter cues that the participants received over the course of progression of the interview from T1 to T3. T1 has an average of 1.91 counter cues, T2 an average of 2.5 and T3 has an average of 2.58. This may be representative of an increase in engagement on the participants' part to sustain their arguments as I presented them with more counter cues.

S.No	Participant	M/F	No. of Counters Cues	T1	No. of Counters Cues	T2	No. of Counters Cues
R1	Lavanya	F	1	U	3	U	3
R2	Sravani	F	1	U?	3	U	2
R3	Gayathri	F	3	Y	3	Y	3
R4	Vishnu	M	2	Y	1	U	2
R5	Yougesh	M	3	Y	4	U?	1
R6	Eshwar	M	2	U	2	Y	4
R7	Akshita	F	2	Y	4	U	5
R8	Sailaja	F	2	U	2	Y	3
R9	Soujanya	F	2	U	4	Y	4
R10	Mathew	M	2	Y	1	Y	1
R11	Mani	M	2	U	2	Y	1
R12	Suresh	M	1	Y	1	Y	2

Table 1. Number of Counter Cues and Shift in Stance
Y=Yes, N= No, U= Undecided, U? = Undecided but questionable

A study of the nature of their shifts within the details of their interactions shows that the shifts from one argument to another may be looked at as three different kinds. The first kind of shifts include the participants (R12 in T1 and R5 in T3) that were reticent during the course of the topic in discussion. This reflects changing of stance almost as soon as a counter cue was given. The participants demonstrating a second kind of shift (R4, R6, R9 and R11) are significant because they justified their shifts in stance by directly stating the counter cues as justification, but did not yield as readily as in the first case. The third kind of shift was from participants (R1 and R5) that gave reasons that they did not draw from the informational counter cues that I gave them, but rather came up during the process of invocation of their reasoning.

> (Lavanya, R1, has been stating that she thinks local markets are better and has been giving her reasons for her opinion. Following is the excerpt from when she is given the third counter cue.)
> Interviewer: 67% of the people are saying it's good for India, and 36% are saying that it's not. More people are saying it's good for India. Do you think local markets are better still?
> Lavanya: No, supermarkets are better. (laughs)
> Interviewer: (laughs) Okay.
> Lavanya: Supermarket have very fresh vegetables. In local market, they put vegetables on roadside. All vehicles are coming or going. That's why.

There were only two respondents (R4 and R9) who did not change their stance during the course of argumentation with them. Soujanya (R9) seemed especially persistent with her opinion (for T3) that local markets are better. I presented four counter cues to her and yet her opinion was the same. She appeared to be resorting to her personal experiences the most to strengthen her arguments. Similarly, R4 persisted with his stance for T3 as seen below:

> Interviewer: ...that lets customers scan products and pay through the app. So customers will go use their mobile phone on the...pick one from the shelf, use it, use their app, and quickly put it in their cart, and their bill is made immediately. So it's very time efficient.
> Student: In supermarket?
> Interviewer: Hm
> Student: Haan, yes sister. In local mark-
> Interviewer: Do you still think local markets are better?
> Student: Yeah, local markets only better. In supermarket, they buying... they not give extra. They wasting their times. I want this money, they requesting. Please give give...they requesting, that's not good. That's why they buying in Saturday markets, local markets.

The analysis of the participants so far, in terms of their shifts in stance, or lack of it, depicts that they do hold beliefs and opinions of their own and can make arguments to defend their stances. To this end, they may borrow from the information that is provided to them or they may utilize their own personal experience or knowledge to uphold these stances. This quality of their responses itself is indicative of the conceptual involvement that the interaction could garner from them. Their production of independent reasoning depicts an understanding and readiness on their part with respect to engagement, as shown in the case based analysis below.

Participant Reasoning	**Key words/phrases used**	**Vegetarian food is better**	**Non-vegetarian food is better**	**Other**
Personal preference	"I like it."	R1, R4	R2	
Health	"More nutrition." "Proteins, vitamins." "Health" "Energy"	R1, R2, R4, R6, R8	R3, R5, R7, R12	
Both	"We should eat both."			R2, R3, R4, R5, R7, R9, R11
Villagers eat vegetarian food while city-dwellers eat more non-vegetarian food.				R4

Table 2. T1: Is it better to be a vegetarian or a non-vegetarian?
R = Respondent

For T1, five students claimed that vegetarian food is better due to health reasons, and four students claimed non-vegetarian food is better for similar reasons. Their reasons across both stances involved key words like 'energy', 'proteins and vitamins', 'nutrition', etc. (See Table 2). This sort of a clustering may be observed in their responses to the other topics as well. In the case of video games (T2), the reasons that eight participants gave for the argument that video games are bad were related to studies or completion of home-work or other work. The next type of arguments was related either to violence or health, both of which were also types that the informational cues readily countered. (See Table 3)

Participant Reasoning	**Key words/phrases**	**Video games are good**	**Video games are bad**	**Other**
Hampers studies/Homework/ Work	"They will not study." "Cannot concentrate in studies." "Not reading"		R1, R2, R3, R4, R6, R7, R9, R12	
Wastes Time			R2, R4	
Violence	"Interest in fighting" "Saying bad words" "Fight"		R1, R2, R5, R9	
Health	"Affect eyes" "Mind not peaceful" "Addicted"		R3, R5, R9, R11	
Entertainment	"Time pass" "Entertainment"	R7, R8, R10		
Reprimand	"Parents will scold us."		R7, R9	
Can be good or bad				R9
Lack of knowledge	"I don't know" "I don't play"			R1, R3, R5

Table 3. T2: Are video games good for us or bad for us?
R= Respondent

Participant Reasoning	Key words/phrases	Supermarkets are better.	Local markets are better.	Other
Distance	"Supermarkets are far."		R1, R5, R7	
Affordability	"People don't have money" "Costly" "Cheaper"		R1, R2, R4, R9, R11	
Variety	"Variety" "All"	R3, R6	R1	
Fresh Vegetables	"Fresh" "Dirty vegetables" *in local markets due to* "pollution, dust on the road" "Vegetables not covered"	R1, R5, R7, R8, R10	R12	
Economic divide	"For rich people, they will go to supermarkets"			R2, R3, R4, R8
Efficiency	"Take much time in local markets"	R3, R6, R7, R8		
Flexibility			R4	
Development	"Farmers are poor"		R9, R11	

Table 4. T3: Is it better to have supermarkets or local markets in the city?
R= Respondent

For the third topic, the clustering can be seen as divided between four reason-types (See Table 4). Five participants state affordability as the reason local markets are better. Five of them who, at some point, wished to argue for supermarkets being better, state the reason as availability of fresh vegetables in supermarkets as opposed to local markets where vegetables may be "dirty" due to ongoing pollution on the road. Four participants state supermarkets and local markets as being meant for people with different economic backgrounds, and thus provide no clear orientation towards either. This last group could be according a multiplist nature (Kuhn, Cheney & Weinstock, 2000) to the category "better", suggesting that comparing of the two entities would mean different things to people from different backgrounds, but the area requires more detailed study.

CONCLUSION

The analysis of interactions with the participants demonstrates a conceptual engagement and evidence of presence of elements of argumentation in the defenses of their stances. The argument put forth by participants in the study were also reflective, to the extent that the design of the study allowed, of the sources that the participants' arguments originated from. The responses of the participants stemmed from their personal experiences and prior knowledge, and this observation stands in line with studies that assign domain specificity to nature of argumentation in children (Kruglanski & Gigerenzer, 2011). This insight makes it imperative for the elements of the context of the child to be explored in line with the nature of argumentation. Their arguments also brought out a certain deeper epistemological understanding of multiplist kind of 'knowing' in them. This finding lends a hand for teaching practices that may be based on understanding how children's epistemologies can have a non-absolutist (possibly empathetic) nature, rendering complexity to the scope of their learning. Further research, thus, would require looking into the nature of arguments children offer in argumentation and the sources of it, sources of inhibitions that children face in scenarios of argumentation, and contextual and content-related cues and determinants of the epistemological process of meaning making in children.

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MEANINGFUL PROBLEM SOLVING WITH SCHEMA BASED INSTRUCTION

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Problems are crucial in physics learning because they are essential for enhancing the depth of conceptual understanding in the learner. The best means to understand a concept in Physics is by presenting that concept as the part of a problematic situation. This study examined the effects of a Schema Based Instruction on Problem Solving Ability in Physics among grade 11 students. A quasi-experimental pre-test, post-test non-equivalent group design was used. Two intact classes with a total of 114 students (60 in experimental group and 54 in control group) doing science course from two Government Higher Secondary Schools of rural background following NCERT syllabus were randomly assigned to either experimental or control group. The experimental group was taught problem solving through Schema Based Instruction, while the control group was taught through Direct Translation Strategy of teaching problem solving. Results indicated that Schema Based Instruction significantly increases the problem Solving Ability in Physics of grade 11 students better than the Direct Translational strategy of teaching problem solving.

INTRODUCTION

Physics students have this notion “I understand the concepts, but I just can’t solve the problems.” Young, Freedman, Ford and Sears (2004) say that in physics, “truly understanding a concept means being able to apply it to a variety of problems.” For effective and meaningful learning, the students must encounter various contextual problems. So it is meaningless to teach or learn physics concepts merely as a textual meaning or definition without giving due weightage to the problem solving process.

Researchers and educators regard problem solving as a necessary 21st century skill. In most disciplines the knowledge that is not used for problem solving tasks is too quickly forgotten within short time (Jonassen, 2010). Therefore the real goal of education in every educational context should be to engage and support meaningful problem solving. Unfortunately the traditional methods like Direct Translation Strategy for problem solving do not support meaningful problem solving. Some students and inexperienced teachers indeed think that the best way to solve problems in physics is to get equipped with a battery of equations and formulae that suits every problem situation. This notion regards problem solving as an answer getting process, not meaning making (Wilson, Fernandez and Hadaway, 2001). Problem solving is not a simple cognitive process like memorizing equations and mathematical operations. It includes a complex set of cognitive, behavioral and attitudinal components (Bautista, 2013).

Physics problems require careful analysis and interpretation of the problem scenario. The cognitive activities i.e. understanding a problem and organizing all relevant information meaningfully play a vital role in problem solving process. Jonassen (2010) argued that problem solving as a process has two critical attributes: first the mental representation of the problem (known as problem schema) and second the manipulation and testing of the mental representation in order to generate a solution. Successful problem solving requires domain of specific knowledge that includes both conceptual and procedural knowledge. Organization of conceptual knowledge and procedural knowledge of a type of problems in a meaningful pattern provides mental representation (schema) of that problem type. This mental representation of problems is the basis of successful problem solving (Chi, Feltovich & Glaser, 1981; Fuch & Fuch, 2005; Jonassen, 2004). Thus for meaningful problem solving to occur, students have to construct problem schema of the problem and to apply the correct problem solution plans based on those schema (Jonassen, 2010).

Review of earlier works on Schema Based Instruction discloses that “Schema Based Instructional Strategy” is an effective instructional strategy for promoting problem solving skill. Using a pretest–intervention-posttest–retension design, Jitendra, Star, Dupuis and Rodriguez (2013), studied the effect of Schema Based Instruction on Mathematical problem solving performance of seventh grade students. The study results demonstrate that Schema Based Instruction was more effective than students’ regular mathematics problem solving instruction. Fang (2012) considered Schema Based Instruction as one of the most supported strategy for teaching word problem solving. Jitendra and Star (2011) claim schema-based instruction (SBI) as “an alternative to traditional instruction for improving the mathematical problem solving performance of students with learning disabilities (LD)”. Schema strategy is a practical approach for training students with learning disabilities in solving word problems (Jitendra, DiPipi, and Perron-Jones, 2002)

PROBLEM SCHEMA

The concept problem schema means knowledge structure used to identify type of problem being solved (Rumelhart & Ortony, 1977). It is the mental representation of the pattern of information that is represented in the problem (Riley & Greeno, 1988). Researchers (Jonassen, 2010; Marshall, 1995;) have studied the role of problem schema on meaningful problem solving and found that a robust problem schema includes situational characteristics and structural information about the problem. According to them, most successful problem solvers are those who can integrate the situational and structural characteristics of the problems. Problem schema could act as a facilitator for improving problem solving skills in learners. If novices learn to organize all relevant information about different problem types in a meaningful and sequential pattern, information will be effectively and easily retrieved while solving problems. So the development of an Instructional strategy that enables novices to develop the same problem schema as conceived by the expert problem solver will enrich meaningful problem solving.

In the present paper the researcher designed Schema Based Instructional Strategy for teaching problem solving in Physics and examined the effect of the strategy, to increase Problem Solving Ability in Physics among grade 11 students. The investigator also designed schema diagram of various problem types included in the selected topics (example is given in Appendix 1). The design of Schema Based instructional strategy is an attempt to integrate the situational and semantic information of the problem. The design of the instructional strategy was based on the schema theory. According to Schema theory of problem solving, the problem solving ability depends on construction and development of schema of problems.

SCHEMA BASED INSTRUCTION

Meaningful Problem solving in physics requires not only calculation accuracy but also the comprehension of textual information, the capacity to visualize the data, the capacity to recognize the semantic structure of the problem, the capacity to sequence their solution activities correctly and capacity and willingness to evaluate the procedure that they used to solve the problem (Lucangeli, Tressoldi and Cendron, 1998). This implies that other than providing for calculations, the design of problem solving learning environment for Physics problems should include means to view the problem holistically to extract meaning from text, to construct situational model of the problem, to casually relate the data sets with structural configuration of the problem, to map the structure with readymade algorithms and to reflect upon the result of applying the algorithm on the basic premise of the problem.

In an attempt to make problem solving more meaningful, the investigator designed a Schema Based Instructional strategy. Schema based instruction is a method of teaching problem solving that emphasizes on both the semantic and mathematical structure of the problem. It utilizes recognition of key words (does a simple key-word strategy) but goes further than simple recognition to stress understanding of the situation represented in the problem (Marshall, 1995)

The composition of this instructional strategy has five basic components: the problem type, the structure map, problem schema, worked examples and practice problems. In this study the investigator classified problems in the selected topics: 'Work, Energy and power' in to following eight problem types: work, kinetic energy, potential energy, work-energy theorem, conservation of mechanical energy, conservation of linear momentum, mechanical power, and kinetic energy & linear momentum conservation. The classification was done based on the structural relationships embedded in the problems. The structure map is a network of the interrelationships between the different physical quantities in the problems (Gentner, 1983). Before attempting problems the learners should get acquainted with the structure map of each problem type (Example of structure map of problem type 'Work' is given in Figure 1)

Constructing and developing schema of each problem type is one of the crucial processes in problem solving. In this study, the investigator designed schema diagram of various problem types included in the selected topics. This schema diagram consists of the following attributes of robust problem Schema suggested by Jonassen (2010): Situation Model (consists of key features of problem scenario and its interpretation); Structural Model (represents inter-relationship between problem elements); and Arithmetic Model (represents required mathematical formula). A problem Schema represents a type of problems that can be tackled using it. Example of general framework of a Problem Schema of 'Work' type problems is given in Figure 2.

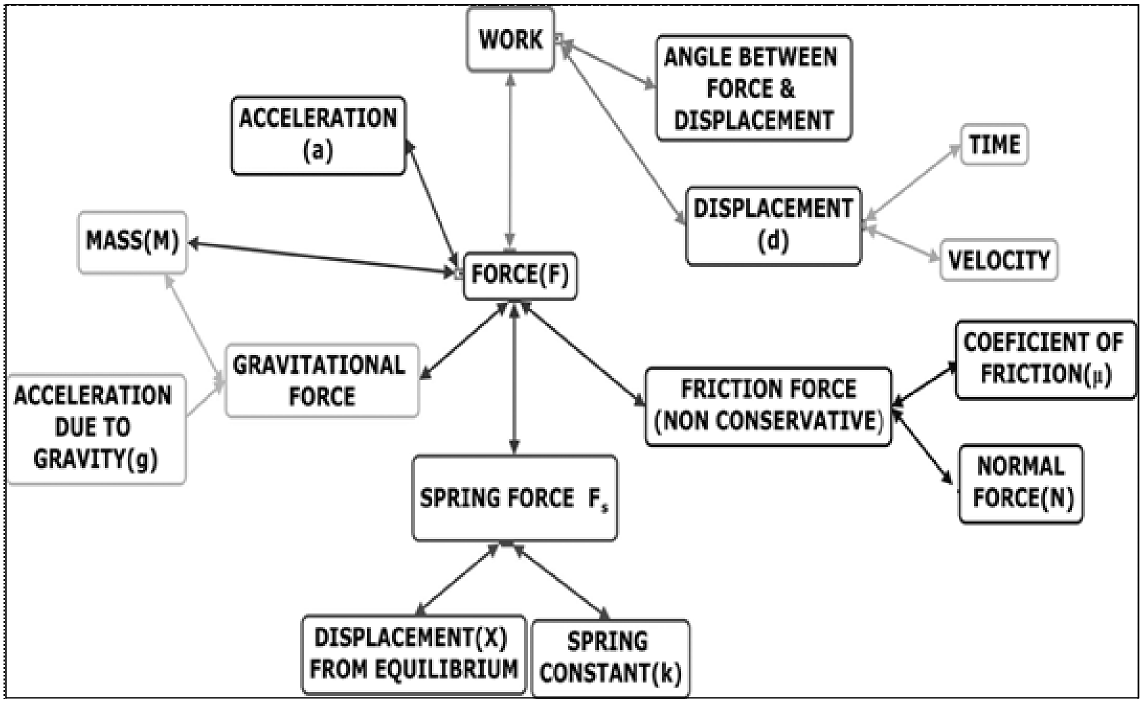

Figure 1: Structure map of problem type 'Work'

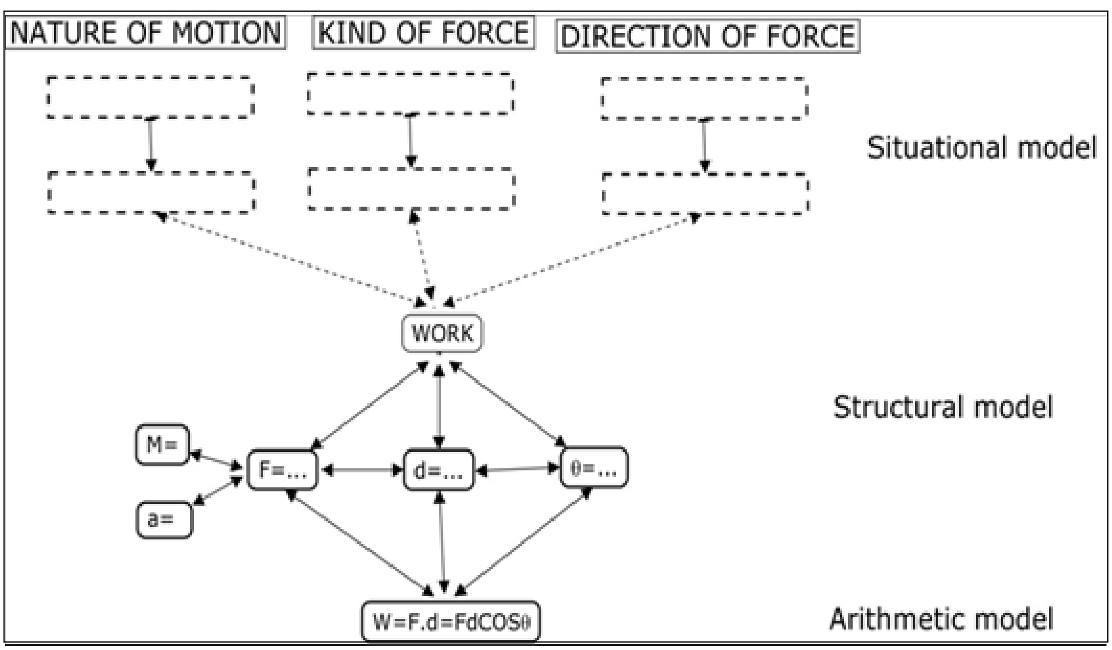

Figure 2: Problem schema of Problem type 'Work'

Physics problems require close reading of the statement to analyse the situations presented in it. This helps to get a feel of the problem and helps to identify the type of problem. Once we identify the problem type, the associated problem with the inclusive concepts and relations come in to our mind. This problem schema can be in the form of a readymade template for a problem type. Whereas this template serves as a basic structure to solve all problems of the type, it has to be outfitted with situational aspects as well as data sets to truly represent the problem at hand.

The 3rd component of the Schema Based Instruction is worked example. This involves hand holding the learner for walk through over the customized sequence of the schema based problem solving procedure. And the last component of Schema Based Instruction is the Practice problem. Practice problem helps learner to apply the newly learned skill in to practice. It gives them confidence to transfer the problem solving skill to new unfamiliar problems in the content domain.

The design of the Schema Based Instruction consists of the following phases:

1. Preparation for problem solving: The intention of this phase is to prepare the learner to solve problems of each problem type with the support of problem schema. In this phase Students are asked to list out familiar and unfamiliar concepts embedded in the problem scenario. They are also asked to draw situation diagram of the problem.

2. Familiarizing with problem types: The development of the situational and semantic information of a problem type and mapping all problem relevant information on to the problem schema of problem type are part of this phase. This includes understanding the concept embedded in the problem, identifying situational elements needed to solve the problem, identifying correct structural relationships in the problem, identifying the appropriate Problem schema.

3. Familiarizing with situationally dissimilar and structurally similar problems: Situationally dissimilar problems aid in recognizing the conceptual elements and to integrate it with the problem schema of the problem type. This phase includes comparing situational features with the help of situation diagrams.

4. Familiarizing with situationally similar and structurally dissimilar problems: in this phase teacher presents situationally similar and structurally dissimilar problems. Students are requested to select problems that can be solved with schema-1 (of type-1 problem). Students are also asked to formulate arguments for their selection of problems.

5. Practicing problem solving using problem schema: in this phase students are asked to practice problem solving by identifying key features of problem situation, drawing thumb nail sketch of problem scenario, identifying relevant data, identifying major concepts embedded in the problem, and identifying correct mathematical equations and operations.

DIRECT TRANSLATION STRATEGY OF PROBLEM SOLVING

According to Jonassen (2010), Direct Translation Strategy is a “form of problem solving that typically involves reading a well-structured story problem, attempting to identify the correct equation, inserting values from the problem statement into formula and solving for the unknown value." (p.308). In this strategy students learn to "directly translate the key propositions in the problem statement into a set of computations" (Jonassen, 2010, p.28).

OBJECTIVE OF THE STUDY

To find out the effect of instructional strategy (Schema Based Instruction/ Direct Translation Strategy of problem solving) with Non-Verbal Intelligence and Logical Mathematical Intelligence as covariates on Problem Solving Ability in Physics among grade 11 students.

METHOD

Quasi-experimental pre-test- post-test non-equivalent group design was used in the study. The symbolic representation of the design of the Experimental phase of the study is given below

$$G_1 \ O_1 \ X \ O_2$$
$$G_2 \ O_3 \ C \ O_4$$

Where, O_1, O_3 – Pre-tests; O_2, O_4 –Post-tests; G_1- Experimental group; G_2 -Control Group; X-application of experimental treatment; C- application of control treatment

Participants

Two intact class divisions of 114 students (60 in experimental group and 54 in control group) of grade eleven students doing science courses from two Government Higher Secondary Schools (Government Higher Secondary School Cheemeni and Government Higher Secondary School Vellur from Kasargod and Kannur districts in Kerala respectively) of rural background following Kerala state syllabus, were selected as the participants.

Research Instruments

The following standardized tests were used for the present study:

1. Standard Progressive Matrices (1996 Edition, prepared by Raven, Court and Raven published by Oxford Psychologists Press, Lambowne House, Oxford, UK): This nonverbal test is intended to measure the subjects' ability to discern and utilize a logical relationship presented by nonverbal materials.

2. Logical Mathematical Intelligence Test (prepared by the investigators): To measure the Logical Mathematical Intelligence of the subjects, a test was developed based on Logical Mathematical components of the theory of multiple intelligence proposed by Gardner (1983). Reliability of the test was established by the test retest method, on 31 grade 11 students doing science courses. The test-retest reliability coefficient was 0.74. The validity of the test was estimated empirically by comparing the scores of the test with Raven's standard progressive Matrices on a group of 48 grade 11 science students. The coefficient of correlation so obtained was 0.59.

3. Problem Solving Ability Test (prepared by the investigators): This test contained 14 Physics problems from the topics 'Work, Energy and Power'. Reliability of the test was established by the test-retest

method on 54 grade 11 students doing science courses. The test-retest reliability coefficient was found to be 0.77. Content validity was ensured by obtaining the judgment of four experienced higher secondary school physics teachers and three physics teachers in collegiate education from Kasargod and Kannur districts of government and aided sectors. Concurrent validity was estimated empirically by correlating the test scores of 54 grade 11 science students with their scores of Problem Solving Ability test developed by Praveen (2017). The coefficient of correlation so obtained was 0.64. Intervention study was performed to confirm construct validity (Brown, 1996) of Problem Solving Ability test.

All tests were administered as paper-pencil tests with appropriate time restriction.

Statistical Technique

Since the experiment was conducted using intact study groups of students of grade eleven, it was suspected that differences in Nonverbal Intelligence and Logical Mathematical Intelligence among subjects would influence the relation between instructional strategy and Problem Solving Ability in Physics. In the present study ANCOVA was used to remove statistically the effects of the extraneous cognitive variables (Non Verbal Intelligence and Logical Mathematical Intelligence) which would have an effect upon the dependent variable: Problem Solving Ability in Physics.

Data Collection Procedure

The investigator himself taught both the experimental group and control groups. The experimental group was taught through Schema Based Instruction. The students were taught the content of chapter 'Work, Energy and power' in the usual expository method of teaching and the problems were dealt in the Schema based method of instruction. The way of teaching Physics problems in the schema based instruction followed the same phases described in the design of schema based instruction. The control group was taught using the Direct Translation Strategy of teaching problem solving. The investigator himself taught the theory and problems of the content portion. The students were taught the content portion of the chapter Work, Energy and Power followed by the worked out problems. The very same set of problems given to the experimental groups were administered to the control group also; but in the usual way of Direct Translation Strategy of teaching problem solving. This would mean that the interventions in the groups differed only in the pattern of instruction of solving problems whereas the learning experiences employed to teach the subject matter remained the same in all the groups. Also the investigator could do justice to the experimental as well as the control groups by teaching them the very same set of problems for work out as well as for practice. The time taken for the entire treatment session was four weeks for each of the study groups. The standardized test for assessing Problem Solving Ability was re-administered in both groups after the completion of the treatment period.

RESULTS AND DISCUSSION

Effect of Schema Based Instruction on problem Solving Ability in Physics:

Table 1 gives the basic properties of the dependent variable Problem Solving Ability in Physics for the experimental and control groups.

Study group	n	Pretest		Post test	
		Mean	SD	Mean	SD
Experimental group	60	4.02	1.27	18.21	3.70
Control group	54	3.78	1.47	11.70	2.31

Table 1: Distribution of Pre-test and Post-test Problem Solving Ability in Physics

Table 1 shows that the mean and standard deviations of the pre-test scores of Problem Solving Ability in Physics among the study groups do not vary too much. But the mean post test score of Problem Solving Ability in Physics varies among the study groups. This is due to the effect of the intervention applied in the groups.

The effect of instructional strategy (Schema Based Instruction/ Direct Translation Strategy of teaching problem solving) with Non-Verbal Intelligence (NVI) and Logical Mathematical Intelligence (LMI) as covariates on Problem Solving Ability in physics for higher secondary school students was tested using one way ANCOVA. The results are presented in Table 2.

Source	Sum of squares	df	Mean square	F	Sig.	η^2_p
NVI	9.03	1	9.03	1.01	0.33	0.01
LMI	57.84	1	57.84	6.49	0.02	0.04
Instructional strategy	1134.69	1	1134.69	127.29	0.00	0.54
Error	980.58	110	8.91			

Table 2: Summary of ANCOVA of Problem Solving Ability in Physics for experimental and control groups

From Table 2 it is clear that the covariates - Non Verbal Intelligence and Logical Mathematical Intelligence - have no statistically significant effect on Problem Solving Ability in Physics for experimental and control groups at .01 level [for NVI: $F(1,110) = 1.01$, $p = 0.326$, $\eta^2_p=0.01$; for LMI: $F(1,110) = 6.49$, $p = 0.012$, $\eta^2_p = 0.04$]. There was a significant effect of instructional strategies on Problem Solving Ability in Physics, after controlling for the effect of Non Verbal Intelligence and Logical Mathematical Intelligence at .01 level [$F(1,110)= 127.29$, $p< 0.001$, $\eta^2_p = .54$]. The partial eta squared value indicates the effect size is large.

Comparing the estimated marginal means showed that the experimental group (which received Schema Based Instruction) has the higher mean of post-test scores in Problem Solving ability (M=18.29; CI=[17.50,19.07]); compared to control group, (M = 11.61; CI=[10.78,12.44]). Thus the ANCOVA result reveals that Schema Based Instruction is effective in increasing Problem Solving Ability in Physics compared to the Direct Translation Strategy of teaching problem solving.

CONCLUSION

In the present study the investigator attempted to validate a Schema Based Instructional strategy for its effectiveness on enhancing Problem Solving Ability in Physics among grade 11 students. It is ascertained that the Schema

Based Instruction significantly increases the Problem Solving Ability in Physics of grade 11 students, compared to the Direct Translation Strategy of teaching problem solving. Therefore the present study suggests the use of Schema Based Instruction for teaching problem solving. If a problem solving learning environment could be prepared by expert teachers using the elements of Schema Based learning, it could benefit the students to increase Problem Solving Ability in physics. This study clearly proves that the Direct Translation Strategy of teaching problem solving is not useful in improving Problem Solving Ability in Physics compared to Schema Based Instruction. Schema Based Instruction takes care of teaching problem solving in a meaningful way.

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CONSIDERING A CONTRASTING CASES APPROACH TOWARDS DEVELOPING A RELATIONAL UNDERSTANDING OF THE EQUAL SIGN IN EARLY YEARS

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The reported study compared two instructional approaches for teaching elementary school students the relational meaning of the equal sign. The primary goal of the larger study, from which the data in this paper are reported, was to examine whether instruction that involves comparing the equal sign with contrasting relational symbols (the greater than– and the less than–signs) is more effective at fostering a relational view of the equal than instruction that focuses on the equal sign alone. Preliminary findings indicate the promise of using a contrasting cases instructional approach to promote appropriate learning about the ubiquitous equal sign in second grade.

THEORETICAL FRAMEWORKS AND SIGNIFICANCE

The theoretical underpinnings of this study are rooted in two areas of research in mathematics education: research focused on developing an appropriate understanding of the equal sign and research on contrasting cases approach to the teaching and learning of mathematics.

Understanding the equal sign in elementary school

Developing an understanding of mathematical equivalence is foundational to success in algebra (Blanton, Stephens, Knuth, Gardiner, Isler, & Kim, 2015; Knuth, Stephen, McNeil, & Alibali, 2006). Unfortunately, years of research indicate that the equal sign remains largely misunderstood by young children (Behr, Erlwanger & Nichols, 1980; Carpenter, Franke, & Levi, 2003; Hattikudur & Alibali, 2010), with most elementary school students perceiving it as a request to compute (operational view) rather than a symbol indicating an equivalence relationship (relational view). For example, in equivalence problems with operation on both sides, such as 2 + 3 + 4 = __ + 4, children typically place either a 9 (adding addends on the left side) or 13 (adding all the addends on both the sides) in the blank. The relational understanding is essential not only for competence in arithmetic problems, but also for success with algebra (Carpenter, Franke, & Levi, 2003; Knuth, Stephens, McNeil, & Alibali, 2006), with an earlier developed understanding leading to better competence in algebra in later grades. It is also essential for success with non-standard arithmetic problems where the unknown appears in a place other than after the equal sign (e.g., 2 + _ = 4). As such, overcoming the misconception of the equal sign as an operational symbol early, before it becomes resistant to change (McNeil, 2014), is a crucial educational goal.

In fact, the Common Core Standard for Mathematics identifies that students should be able to interpret the meaning of the equal sign by the end of first grade (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). Given this goal, the absence of explicit attention to the meaning of the equal sign in popular U.S. curriculum is concerning (Powell, 2012). The problem is exacerbated, as many preservice teacher textbooks offer little explanation about how to teach students about the equal sign (Li, Ding, Capraro, & Capraro, 2008). Furthermore, students are typically introduced to equal sign and symbols of inequality in the same grade. Thus, comparing and contrasting the equal sign to symbols of inequality may help in making sense of these symbols as relational in nature.

Contrasting cases to support mathematics learning

Researchers have used comparison of solution methods to promote understanding of abstract mathematical ideas (Rittle-Johnson & Star, 2007; 2011). While comparison of solution methods has been used for almost a decade in classrooms, research in recent years has evidenced promising effects of using comparison towards developing students' understanding of concepts underlying abstract mathematical symbols (Aqazade, Bofferding, and Farmer, 2016; Aqazade, Bofferding, and Farmer, 2017). For example, Aqazade, Bofferding, and Farmer (2017) found that second graders' who contrasted the cases of adding two positive integers and adding one negative and one positive integer were able to change their understanding of negatives in addition problems. With respect to the equal sign, there is evidence to support that contrasting the equal sign with symbols of inequality can help in shifting students' view of the equal sign from an operational to a relational symbol (Hattikudur & Alibali, 2010). The researchers found that third- and fourth- grade students who received instruction about comparing the three symbols made greater gains on conceptual tasks (that involved seeing the equal sign relationally) than those who received instruction on equal sign alone.

This study was motivated by the promising findings of Hattikudur and Alibali's work and was aimed at exploring the effects of using such an approach in early grades. The primary goal of the larger study was to examine whether comparing the equal sign with its contrasting symbols (the inequalities) is advantageous over explicit focus on the equal sign alone among first- and second-grade students who are arguably less entrenched in operational view of the equal sign (McNeil, 2014). In this report, preliminary findings on the effects of using comparison on second grade students' understanding of the equal sign as measured by their performances in solving equivalence problems is discussed.

RESEARCH QUESTION

Does instruction involving the use of a contrasting cases approach: specifically, comparing and contrasting the equal sign (as a symbol of quantitative equality), with the greater than- and the less than- symbols (as symbols of inequality), promote learning any differently than instruction without a contrasting cases approach in second-grade students?

METHOD

Participants

Participants (n=36) were recruited from two second-grade classrooms in one public elementary school serving a small mid-western community in the U.S. Participation was voluntary and required parent and student permission. Approximately 72% were eligible for free or reduced lunch and 49% were females.

Procedure

Students from each classroom were randomly assigned to one of the two conditions: (a) the *contrasting cases* group received instruction on comparing the equal sign with the greater than- and the less than- sign; and (b) the *equal sign only* group, that also acted as an active control and received instruction focused on using three separate definitions of the equal sign as a relational symbol. The number and type of problems seen by students in the two conditions were identical. Time spend on activities during sessions and any instruction, where applicable, were comparable across the conditions and were video recorded.

Students participated in a total of three one-on-one sessions. The first session was approximately 55 minutes long, and included: pretest, a short break, a lesson based on the group assignment with a discussion portion where students were introduced to the contrasting symbols or equal sign, and a session-exit test. During the second session, students discussed and identified how the contrasting symbols were similar and different, sorted a set of cards with number statements into a true or a false pile (e.g., sorting whether $2 + 5 = 1 + 6$ belongs to the true or false pile) and reasoned why they identified the statement to be true or false. The third session was similar to the second session and ended with a posttest that included problems similar to pretest as well as transfer problems.

PRELIMINARY RESULTS

The outcome measures reported here consisted of students' performance on solving equations, in particular on solving equivalence problems with operations on both sides and one unknown, as well as the reasoning they used to arrive at their answer. Responses were coded for both correctness and the underlying way of reasoning the child used. The coding scheme for students' reasoning was based on a scheme used in prior research (Knuth et al., 2005; Hattikudur & Alibali, 2010). Out of 36 students, one did not complete all three sessions and was excluded from the study.

At pretest, with the exception of two students, all students got zero correct on equivalence problems. This is consistent with previous research (McNeil et al., 2012), which indicates that children typically fail on equivalence tasks, and this has been attributed to children having an operational view of the equal sign (McNeil & Alibali, 2005). Indeed, the majority of the students (98%) indicated an operational view, in their strategy choice by either combining the addends on the left side of the equal sign or adding all the addends when asked to describe how they figured out what the unknown on the pretest.

At posttest, Levene's test for homogeneity of variances revealed unequal variances and hence a one-way-Welch ANOVA was used. The analysis revealed that there were statistically significant differences in posttest scores across the instructional groups, Welch's F (2, 38. 31) = 4.79, $p = .007$. A Games-Howell post-hoc comparison (at $p < .05$) indicated that the students in the comparison condition (m = 4.68, s.d. = 3.67) performed marginally significantly different than students in the equal sign only condition (m = 3.10, s.d. = 3.32).

Identifying patterns in performance on equivalence problems

It must be noted that almost all students had zero correct on the pretest. At the posttest, the students ranged from getting some problems correct to getting all correct, with the bulk of students getting either all or all but one problem correct. A smaller number of students got some but not all problems correct, and thus present an interesting case. Initial interpretations of these students' performance suggest that these students might have only begun to consider the equal sign as something other than an operator but have not yet undergone a complete conceptual change in their understanding sufficient to demonstrate consistent performance on all equivalence problems.

To capture variations in student thinking and performance, students' overall performance was categorized into binary levels; with levels of learning defined as a) *satisfactory*, getting at least four problems correct (out of 6) with at-least one novel problem correct; b) *none*, getting none or just one of the posttest problems correct. These criteria allowed examining patterns of learning that may be associated with the different instructional conditions.

Overall, 62% of the participants' demonstrated *satisfactory* learning on the posttest and 21% demonstrated *no* learning. The percentage of participants by instructional condition with levels of learning is provided in Table 1. As can be seen, the percentage of satisfactory learners varied by instructional group, in the following descending order: *contrasting cases* group (54%), and *equals only* group (48%).

Differences in participants' learning as measured by number correct on the posttest was found to be related to the type of instructional condition, $\chi^2(2,36) = 12.15$, $p = .005$.

SUMMARY

The preliminary findings reported in this paper indicate that leveraging a contrasting cases approach to instruction might be useful in promoting a relational understanding of the equal with second graders and may help in circumventing the erroneous operational patterns commonly observed among young learners when solving equivalence problems. Further analysis will reveal how students progressed in their thinking and what aspects within the comparison seemed to bootstrap the notion of equal sign as a relational symbol among students on other equivalence tasks.

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CONCEPT IMAGES OF QUADRILATERALS: A COMPARATIVE STUDY OF VIII AND IX GRADE SCHOOL STUDENTS

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The study attempts to explore the concept images of students regarding quadrilaterals. The analysis is based upon the theoretical frameworks of Fichebein theory of figural concepts, mathematical relationship and classification of quadrilaterals. Findings of the study suggest that in spite of teaching quadrilaterals with a single definition; students came up with variety of definitions which were personal rather than formal. Students used non- critical attributes in non- formal or incorrect definitions. Trapezium and kite received maximum variations in its definitions and images. Findings of the study suggest that hierarchical classifications of quadrilaterals demand attention in school curriculum.

INTRODUCTION

'Quadrilateral' has been described in many ways in mathematics. It is used synonymously for 'Quadrangle' and comes from the Latin *quadric, a combining* form for 'four' and *latus* means sides. 'Quadrilateral' *is defined as 'consisting of four lines, no three of which are concurrent and the six points they determine' (Usiskin and Griffin, 2008)*. Due to the etymology of 'Quadrilateral', it has also been considered to be a polygon with four side as found in many textbooks. Quadrilaterals are formally introduced with its naming at elementary level, first in class VI under the heading of 'basic geometrical shapes' and then in class VIII (named as 'understanding quadrilaterals') and class IX (named as 'Quadrilaterals'). The level of sophistication increases from class VI to IX i.e. from empirical to more axiomatic in nature.

There are number of studies specific to quadrilaterals which built upon Van Hiele levels and in relation to other cognitive aspects. Nakahara (1995) found that an understanding of basic quadrilaterals develops accordance with Van Hiele levels, but it is specific to the geometric figure involved, i.e. level assigned to students may be different for different geometrical figures. Further Transition from level 2 to level 3 has been considered slow and problematic by a number of studies because of the distinguishing feature of level 2 i.e. class inclusion- 'interrelationship between two sets when all the members of the first are members of the second e.g. squares is a subset of rectangle' (Owens & Outhred, 2006) whereas identification of features of a shape and grouping figures based upon a single property are important aspects of level 2 (Clements and Battista,1991; De Villier, 1998;Currie and Peg, 1998; Fujita and Jones,2007). Matsuo (1993) suggested that students' consideration of a square as rectangle depends upon the property they are focused on. If their concept definition consisted of a rectangle having four right angles or parallel sides, there is feasibility that students will consider square as a rectangle and if they consider rectangle with two longer and two shorter sides, square is excluded**.** Researchers aspired to help students overcome difficulties in inclusion tasks, where there is a potential gap between students' geometrical thinking level (Van Hiele, 1986) and task level. For example, the classification of a rectangle as a parallelogram requires Van Hiele's level 3 geometrical thinking (Order), hence students who fail to classify it correctly do not seem to have reached this level (Gal & Lew, 2008). Studies have highlighted the importance of defining and hierarchical classification of quadrilaterals (e.g. De Villier, 1998, 2008; Fujita and Jones, 2007) and argued that formal definitions can be developed at level 3 as at this level, it is expected from students to see the interrelationship between shapes. He has also discussed in his studies that students should be allowed to form visual, uneconomical and economical definitions and should be actively involved in formulations and evaluating definitions. Other studies (Shir & Zaslavsky, 2002; Heinze, 2002; Saenz-Ludlow & Athanasopoulou, 2007; Villier, Govender & Patterson, 2009; Blair and Canada, 2009; Driscoll et.al., 2009) focused on active engagement of students in defining processes such as to analyse definitions; create and critique their own definitions; reason with relationships. These studies have shown that students who are encouraged to participate in defining are able to change their opinions because of interactions as well as justifying and arguing with their colleagues and it leads them to positive gain in understanding nature of definitions and also to think about necessary and sufficient conditions of definitions. Fujita and Jones have emphasized the need of a theoretical framework for the development of definitions and hierarchical classification of quadrilaterals. They argue that a study of hierarchical classification can help in bridging the gap between Van Hiele level 2 and level 3. They also proposed to explore the common cognitive paths of the relationship among quadrilaterals as from their study it was speculated that there could be hierarchical order of the difficulties. For example, they conjectured from their study that it might not be effective to teach the relationship of rectangles and parallelograms before the relationship between rhombuses and parallelograms (Fujita & Jones, 2007).

THE PRESENT STUDY

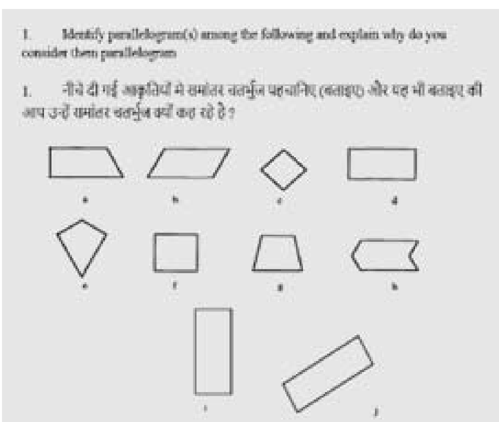
The objective of this paper is to put forth the concept images of elementary and secondary school students regarding quadrilaterals. This research is in consonance with the assertion that Villiers et.al. (2009) states as 'The classification of any set of concepts implicitly or explicitly involves defining the concepts involved, whereas defining concepts in a certain way automatically involves their classification'. Definition and classification are, therefore, important tools for developing the ability of deductive reasoning and proving. It also plays an important role in identifying new mathematical objects with some precision. However, a number of studies reveal that many learners have difficulties with hierarchical classification of quadrilaterals and related formal defining of such shapes because of cognitive complexities involved in such learning (e.g. Monaghan, 2000; De Villier, 1994).This study considers the complex nature of 'figural concept' as a major factor of learners' difficulties with hierarchical classification of quadrilaterals and related formal defining as also studied by Fujita & Jones, (2007). Fischbein states that 'while a geometrical figure (such as a square) can be described as having intrinsic conceptual properties (in that it is controlled by geometrical theory), it is not solely a concept; it is also an image' (Fischbein, 1993, p. 141) implying that a geometrical figure has characteristics of dual nature in that it is both concept and image and the two are closely interrelated. Learners lack the ability to combine interaction between a concept and its image and hence individuals' *personal figural concepts* are formed that *influences* the classification of quadrilaterals. Personal figural concepts are formed on the basis of and individuals' *personal geometric concept definitions* that are shaped by the *concept images* formed in their minds and which are different from *formal conceptual definition* of a geometrical object.

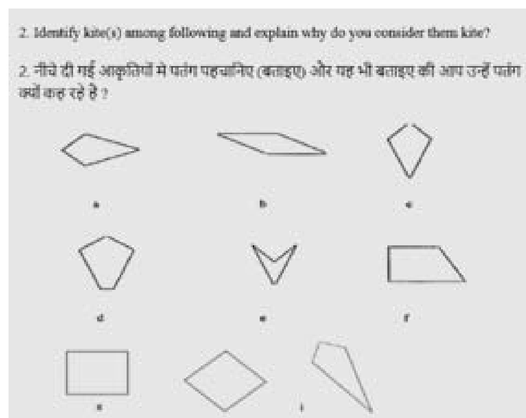
Participants and Setting

The study group consisted of 240 students from 4 sections, each of classes VIII and IX (having 30-35 students in each section) from the two government schools for using worksheets and students' interviews. The government schools had strict admission criteria and had both English, Hindi meduim. However, in spite of having English medium, meduim of instructions commonly used was Hindi. Both English medium and Hindi medium sections were selected for the study. The socio-economic background of students varied from working to lower middle class. Parents' occupations varied from worker in electricity board to, drivers, teachers, farmers, small business to vender etc.

Data Resources

After the topics were taught in the classes by the respective teachers, worksheets related to geometrical tasks were given to students to assess students' understanding of quadrilaterals. The worksheets included items related to (i) Identification of different quadrilaterals and (ii) Defining quadrilaterals.





1. a. Having experiencing from your surroundings and learning from different resources like textbooks, your school or tuition teachers, your friends write down your Ideal definition of the following shapes in your own words:

(i)Polygon, (ii) Quadrilateral, (iii) Parallelogram, (iv) Rectangle, (v) Trapezium (vi) Rhombus, (vii) Square (viii) Kite

b. Also show them diagrammatically

c. Draw and name one example and non-example of these shapes

1. a. आपके आसपास के अनुभव से अपनी पाठ्यपुस्तक, स्कूल अध्यापिका, ट्यूशन अध्यापिका, आपके दोस्त इत्यादि से बातचीत करके या सीख कर, आप नीचे दी गई आकृतियों कि अपने शब्दों में अपनी अभीष्ट परिभाषा दीजिए i) बहुभुज ii) चतुर्भुज iii) समांतर iv) चतुर्भुज v) आयात vi) समलंब vii) समचतुर्भुज vii) वर्ग viii) पतंग

b. इन्हें चित्र द्वारा अंकित जी कीजिए |

c. इन आकृतियों के लिए एक उदाहरण व एक अउदाहरण (जो उदाहरण ना हो) दीजिए |

Figure 1: Worksheets (i) and (ii)

Data Analysis

Data collected through worksheets and interviews was analysed through the process of identifying, coding and categorizing the primary patterns in the data. In the study, students definitions, drawings and reasoning while identifying quadrilaterals were taken into account while analysing students' perceptions. Results were presented in the form of frequencies, students verbatim and their drawings.

Key terms used for the purpose of analysis are as follows:

- Partitional and Hierarchical classification: Partitional classification includes exclusive definitions, which consider concepts involved as disjoint from each other e.g. squares are not considered as rectangle. Hierarchical classification includes inclusive definitions which allow inclusion of more particular concepts as subsets of general concepts e.g. square is classified as a special rectangle
- Formal concept definition: formal is related to mathematically accepted; a concept definition is defined as 'a form of words use to specify that concept' (Tall and Vinner, 1981, p. 152).
- Personal concept definition: It is defined as students' own definitions based upon their own experiences of learning geometry and are different from formal.
- Concept Images: 'The total cognitive structure that is associated with the concept, which includes all the mental pictures and associated properties and processes' (Tall and Vinner, 1981, p. 152).
- Formal figural concept: A 'figural concept' which is associated with formal definitions and formal concept images in geometry.
- Personal Figural concept: A 'figure concept' which is associated with personal concept definitions and one's own concept images in geometry.
- Critical attributes are attributes that must be present for the concept to be formed, while non-critical attributes are attributes that may be present but are not required and has strong visual characterstics.

RESULT AND DISCUSSION

In this section, a comparison of concept images of VIII and IX grade students is provided in relation to quadrilaterals. It has been presented in the light of definitions and drawings and reasoning provided by the participants.

Definitions and Drawings of quadrilaterals of VIII and IX grade students

Definitions and drawings of 'basic quadrilaterals' were analysed to explore the students' personal figure concept. Comparison of the images and definitions of 'basic parallelograms' displayed in table 1.1 shows that the majority of students of classes VIII and IX could draw a prototype image (correct image) of quadrilaterals (with an exception of trapezium), however very less students provided their respective correct definitions. Least correct definitions were provided for 'trapezium' and 'kite'. Interestingly, there was not a significant difference in the frequency of respective responses of class VIII and IX.

Class	Class VIII (%) N=120		Class IX (%) N=120	
Figure	**Image**	**Definition**	**Image**	**Definition**
Parallelogram	98	30	99	31
Rectangle	100	33	98	33
Trapezoid	71	26	86	29
Rhombus	100	32	99	34
Square	100	33	100	33
Kite	93	24	98	28

Table 1: Correct responses of drawing and defining of 'basic quadrilaterals'.

When students' definitions of different quadrilaterals were examined, a variety of definitions were observed ranging from listing critical attributes to describing a figure by its name of shape using non- critical attributes. Maximum variations were observed in the definitions of *parallelogram* and *trapezium.* Interestingly, critical attributes were used for defining parallelogram and non- critical attributes were used for trapezium eg. Trapezium as: *A closed figure made up of two figure(s), a triangle and a quadrilateral*, Student H, class 9). Most of the non- formal (natural speech) but satisfying minimal necessary and sufficient conditions were observed for 'kite'. eg. Definition of kite provided by student G of class IX *Upper two lines are equal and lower two lines which meet each other are also equal.* In this definition, he wanted to explain that adjacent sides are equal.

Analysis of definitions also revealed that 84% students of grade VIII and 48% students of grade IX provided definitions having unnecessary or insufficient conditions required for constructing their respective figures. Examples of students' definitions (interpreted) containing unnecessary conditions are (i) *Quadrilateral: It is a four-sided closed figure, it has no properties of sides and angles. (ii) Trapezium: A line which stands on the other line is called trapezium.* An example of definition consisted of insufficient conditions is as follows: *Rectangle: Rectangle is a parallelogram but parallelogram is not a rectangle.*

This definition is insufficient in the sense that, it tells that the rectangle has all the properties of parallelogram but conditions which makes it rectangle was not mentioned in this definition. It was also seen that among rest of the correct definitions provided by students of both grades, most of the definitions contained more than minimal set of necessary and sufficient conditions, termed as *uneconomical* (Villier. et. al. 2009). An example of uneconomical definition shared in natural language by a student of class VIII is: *A figure which has four sides and it is closed from all sides. its opposite sides are parallel. Sum of all angles is 360°.*This definition contains more properties than required to construct a parallelogram.

Some common factors emerged that influences student definitions are categorized as follows:

Language driven

It was interesting to see that 17% of class VIII and 20% of class IX students' definitions of trapezium were influenced by **its name in Hindi language** 'samlamb' (sam means equal, lamb means perpendicular). Another figure in which it was expected to have the influence of language, i.e. parallelogram as stated by Fujita and

Jones (2007) that students may tend to remember about parallel lines from its name 'parallelogram' but they may have limited perception /understanding of it, definitions of parallelograms were not much influenced by its language. Despite of the fact that the name of parallelogram, may reminds students about parallel lines, 22% of class VIII and 25% of class IX students used criteria of 'opposite sides are equal'. Interestingly, criteria of 'parallelness' were used by more number of students of class VIII (23%) than class IX (13%). Many students used linguistic explanation for parallel as equal distance between two lines or lines never bisect (interpreted meaning intersect). In cognitive sense, definition may be influenced by its name but its concept images may be limited. For e.g. rectangle, rhombus and square are termed as special parallelograms under the hierarchical classification of quadrilaterals; limited perception about parallelogram may not consider them as parallelograms.

Non-critical attributes

To define trapezium, 15% of class VIII students and 12% of class IX students used **non-critical attributes** of its prototypical image e.g.

- Trapezium is made up from two triangles and one rectangle
- One triangle and one rectangle
- Look likes rectangle, but sides are not equal
- Looks like a table or pot
- It has parallel sides and perpendicular height.

Some typical parallelogram's definitions of class VIII students (20%) were influenced by its prototypical image like 'opposite sides equal and bends' or 'opposite angles are equal and angles are more than 90°'.20% of class VIII students and 20% of class IX students used non- critical attributes to define kite. Some typical definitions stated by students are:

- *A figure whose all sides are equal, but it is not a square.*
- When we see it, it looks like a prism?
- (Diamond) is called a kite.

Critical attributes and economical definitions

- Most of the definitions of parallelogram were economical definitions using *equal side criteria*.
- Only 18% students of IX class and 7% students of class VIII defined trapezium as a quadrilateral with *one pair of opposite sides parallel*.
- Definitions of rectangle and square had a strong influence of its prototypical image. Therefore, in both the definition, students did not feel to mention about its angles with other critical attributes of their respective images. Angle is an important attribute of rectangle and square as it differentiates parallelogram from rectangle and rhombus from square. Table 2 shows that percentage of students who defined square and rectangles without mentioning about its angles.

Class	Square- all sides equal	Rectangle-opposite sides equal
VIII	38%	43%
IX	25%	15%

Table 2: Students' definitions of square and rectangle

- In case of 'kite', maximum number of economical definitions were written in students' natural speech' i.e. non- formal definitions, for example, non-formal definitions to explain adjacent sides equal by student G of class IX '*Upper two lines are equal and lower two lines which meet each other are also equal'*.

Analysis of students' drawings indicates that most of the students drew prototypical image of these concepts (except trapezium). It was emerged that students used three different ways of connecting an image with its definition:
- Influence of image on its definition
- Influence of definition on its image
- Influence of name of the figure on its definition and hence on image

Influence of image on its definition
The responses of 31% students of class VIII and 17% students of class IX described quadrilaterals without mentioning whether it is a quadrilateral/a four-sided figure/a simple closed curve. The image has such a strong influence that they did not consider it important to mention this while describing its attributes or properties. Student A e.g. gives the following response when asked to define a square *All its sides are equal, opposite sides are parallel, all sides are equal to each other also. All angles are of 90°. Diagonals bisect each other.* The student, however fails to mention that a square is a kind of quadrilateral or a parallelogram or any other shape. Emphasis on **'its'** shows that the student is focused on the image drawn by him/her. In another example of defining a 'kite', Student B responded that *'Kite is shaped like a rhombus when we rotate it".* In the definition of a rhombus, Student C replied that *all its sides are equal, but its shape is different from a square*. Influence of prototypical image is so strong that the learners feel the need to mention in the definition that it is different from a square. This definition would fall in the category of a partitional classification, i.e. in that it excludes square from the set of rhombus (Villier et.al., 2009). It may be interpreted that concept image of a definition may be responsible for students' exclusive definitions. This connection of image with its definition is has also been borne in the findings of Fujita and Jones (2007).

It was also observed that definitions in natural speech (non -formal) had influence of non-critical attributes of the prototypical images. For example, it was observed in definitions of 33.33 % of class VIII students and 40% of class IX students e.g. Student E defined kite as "*Kite is a shape which has two triangles together and those two triangles are not equal". Another Student F defined kite as* **"***both its vertices are outside, on the top and at the bottom"*. (Here learner wanted to convey that upper and lower vertices of kite are more pointed than left and right vertices). In both the definitions, learners were describing non-critical attributes (attributes which evoke visual image of shape) of kite in its definitions. In the case of the trapezium (42% of class VIII and 30% of class IX) and kite, definitions using non-critical attributes seem to indicate an especially compelling influence on the image. So, for example a student who defines the trapezoid as: *'A closed figure made up of two figure(s), a triangle and a quadrilateral' represents it as in the picture below: (Student H; Class 9)*

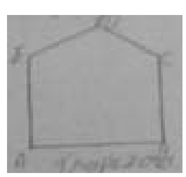


Figure 2: Sample of student's drawing of trapezium

A prototypical image of a trapezium can be decomposed into a triangle and a quadrilateral by joining a vertex with any point on its opposite side. This Student has visualized the decomposed shapes and recomposed it into a pentagon.

Influence of definition on its image

The results also indicate that the definition has influenced the image. There were some typical cases where this connection was clearly visible. For example, Student J defined rhombus as*: A four-sided closed figure with 90°angle is called rhombus. Each side is equal.*

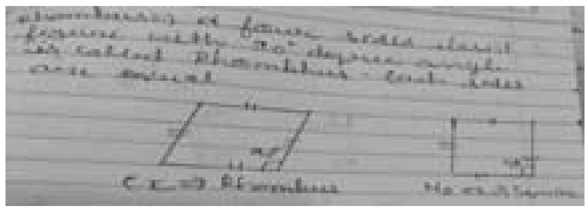


Figure 3: Sample of student's drawing of rhombus

Since the student defined the rhombus consisting of 90° angles, therefore he/she labels the obtuse angles in the figure as 90 degree angles. This connection between image and definition may work if students try to memorize the definition of figure that may lead to mix up properties of some other figure e.g. properties of square in this case are mixed up with properties of rhombus.

Influence of name of the figure on its definition and hence on image

The results also suggest that the name of the figure affects the ways in which students define the figure and also the kind of mental image they created of it. This was mainly observed while defining trapezium by 17% of class VIII students and 20% of class IX students. The trapezoid is called '*Samlamb*' in Hindi, and its literal meaning would be 'equal perpendicular'. Some interesting examples when asked to define a trapezoid student response were as follows: (translated from Hindi)

- *A figure in which one line is perpendicular to the second line.*
- *A line which stands on the other line is called 'Samlamb*

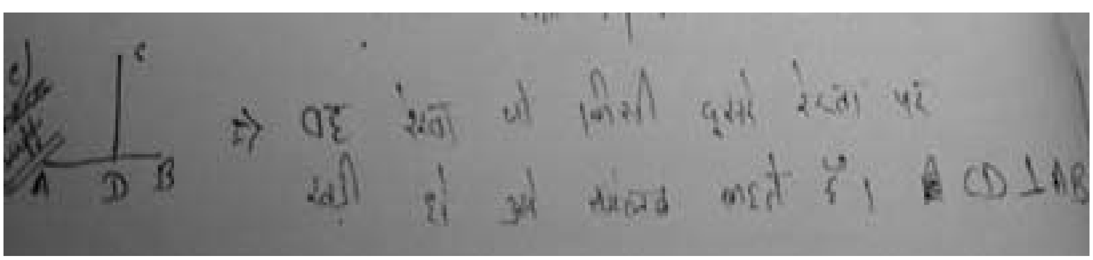


Figure 4: Sample of student's drawing of trapezium

Another example is:

- *Trapezium (Samlamb): A four-sided figure, with four equal sides and all sides make 90° angle, is called trapezium*

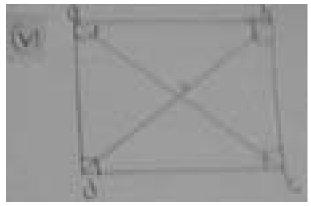


Figure 5: Sample of student's drawing of trapezium

CONCLUSIONS

Data of the study revealed that the students predominately used personal figural concept. There was a considerable gap between formal figural concept and personal figural concept of both classes VIII and IX. These findings are consistent with the finding of research done by Fujita and Jones (2007) ('kite' was not studied by them) and Kawasaki (1992) who studied teacher trainees' personal figural concepts of quadrilateral and found a significant gap between formal *figural* and *personal figural concept* of quadrilaterals. The study suggests interrelationship of quadrilaterals needs to be focussed more in school curriculum.

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DESIGNING AND MAKING ROLLER COASTERS BY INDIAN MIDDLE SCHOOL STUDENTS

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The current article details our observations from two workshops with grade 9 students, working in groups, designing and making a paper roller coaster. The preliminary analysis of our observations indicate that designing an activity around roller coasters has huge potential in terms of giving students first-hand experience of designing, open-ended thinking, exploration and modelling. The activity enabled communication and collaboration between members, engaged them in planning, designing, model-making and executing design ideas.

Keywords: *design education, modeling, making, roller coasters, collaboration*

INTRODUCTION

Maker-centred learning provides opportunities to learners to acquire both critical and creative thinking skills through creating, designing, making and tinkering activities. These activities promote active participation, self-directed learning and encourage taking up of challenges as creative learning opportunities (Clapp, Ross, Ryan & Tishman, 2016). In the context of design problem-solving, a typical maker-centred activity would involve ideation, material exploration and manipulation, mock-ups, model-making, and prototyping. Studies with practising designers have shown frequent use of mock-ups and rapid prototyping (Hess & Summers 2013; Deininger, Daly, Sienko, & Lee, 2017) at different stages of design process to benefit the final outcome. Amongst children, the process of model-making has also been reported to aid in externalising and verbalising ideas that might otherwise be difficult to communicate (Yrjönsuuri, Kangas, Hakkarainen, & Seitamaa-Hakkarainen, 2019).

Context of this study

Roller coasters (RC) are fun rides to be on. They have often been the object of interest for children, even when they have never experienced riding on one. Making and designing RCs is not new to educators (Cook, Bush & Cox, 2017; Jones & Jones, 1995; Ansberry & Morgan, 2008). One finds a variety of activities on science (typically concepts of potential and kinetic energy, velocity/speed, gravity and laws of motion) and engineering design surrounding RCs. However, in the process of implementing such activities in a classroom setting, learners tend to concentrate on the procedural aspects of making their designs, instead of exploring relevant science content and design principles. Vattam & Kolodner (2008) refer to this tendency as the "design–science gap". One may also argue, that procedural prototyping (for example template based or ready-to-use kits) may not be ideal for children who are novices in designing as it might not facilitate learning and mastering fundamental design and engineering skills such as measurement, precision, estimation and approximation (Choksi, Chunawala & Natarajan, 2006).

Although, activities pertaining to designing and making RCs are quite popular in school science education, they are not documented with Indian students, especially from a design perspective. In this exploratory study, we share our observations from two design and technology (D&T) workshops which were conducted with the aim of introducing students to the iterative design process from conceptualisation to making and evaluating.

METHODOLOGY

Two stand-alone workshops of approximately 3.5 hours each were conducted a day apart with grade 9 students. The workshops were planned with a focus on engaging students with design exploration, planning and making skills, collaboration, communication and evaluation.

Participants and Data Collection

The workshops involved Grade 9 students (age group 13-14 years) of Jawahar Navodaya Vidyalaya (JNV) schools from 3 Indian states (Gujarat, Maharashtra and Goa). JNV schools are central government residential schools spread across India, where the medium of instruction is both Hindi and English. There were two batches of students. One batch had 29 (8G, 21B) students and the other 31 students (19G, 12B). Students were from rural, semi-rural and urban backgrounds and many were unfamiliar with others in the batch. Student groups were formed by a random chit-based system. Most of the groups happened to be mixed gender groups with 4-5 students in each group. In total, there were 12 groups which have been named as G1, G2, G3, and so on, in this paper.

Data sources: Field logs from 4 facilitators, informal and formal interactions with students, students' drawings, the RC models made by students, photographs and videos, student presentations, and the worksheets filled by students of workshop 2, served as sources of data.

Procedure, Design Brief and Materials

The workshops were planned to engage students on a D&T task in a playful manner. Workshop 2 (W2) was re-structured after reflecting on the learnings of Workshop 1 (W1). Both workshops started with an initial discussion of students' ideas about D&T. This was followed by a brief 10 minutes presentation on D&T with a focus on iterative and collaborative nature of design. Subsequently, students were involved in the following steps: 1) Practising basic skills (paper folding techniques) needed for the RC design challenge; 2) Brainstorming, planning and making rough drawings of their RC design; 3) Building or Making the RC. 4) Testing and evaluating their RC model by using a marble and revising the models. 5) Demonstrating their final working RC model and communicating it to their peers. There were some differences in the ways the 2 workshops (W1 & W2) were conducted. These differences were: initially, information about the design task was unknown in W1, while it was known in W2. In W1, facilitators engaged the whole class together for making different RC tracks, while in W2, three workstations were setup simultaneously to demonstrate the same. Use of funnel and wide loop was mandatory in W2, but not in W1. A worksheet for reflection was given only to students in W2.

> *Design Brief*: *Imagine you are a roller coaster design team competing to design a new and exciting roller coaster ride for a playground. Your task is to design and build a mini paper model of the ride using the paper folds taught to you. You have to test your ride with the marble provided. The specifications are: 1) The entire roller coaster must fit on the base provided; 2) The marble on your ride should travel for at least 4 seconds; 3) You have to use at least 1 pillar, 1 loop, 1 straight track and 1 L-shaped track. Also, 1 wide loop and 1 funnel (specific to workshop 2); 4) It should be a self-supporting model; 5) Marble should travel from start to end without any external interference.*

Materials provided to students: Coloured paper, scissors, glue, stapler, sticky tape, pencil, scale, a base box with dimensions: length=45cm and width=50.5cm (Workshop 1) and length=29cm and width=38cm (Workshop 2).

OBSERVATIONS AND FINDINGS

Our analysis focused on design process, specifically exploration, generation of ideas, modelling and collaborative designing. Design process was analysed using students' sketches, their final RC models, student discussions and conversations as reflected in our field notes, and photo documentation of the workshops. Insights for evolution of ideas were drawn from students' design explorations and negotiations. Collaborative designing was analysed in terms of distribution of responsibilities and use of verbal and non-verbal communication modes.

Design process and evolution of ideas

Building of a RC as a design challenge was received with a lot of enthusiasm by students. They were focused while learning new paper folding techniques and curious to know how these paper folds can be placed together to make a working RC. After the initial session of demonstration and learning folds, the groups were involved in making a working model, and this required planning and teamwork. The design challenge involved ideation, design and planning, making and testing. D&T education places emphasis on developing technical abilities of students in addition to imparting essential skills like modelling. Stables and Kimbell (2000; 2006) stress the strong interaction between mind and hand during design and making activity, indicating that they are inseparably linked. Harrison (1992) argued that in schools, most making should in fact be modelling. He categorised the purposes of modelling as i) aids in thinking, ii) communicating form or detail, and iii) evaluating a design or selecting its features.

The process of constructing the roller coaster: All the teams were encouraged to make a design sketch of their RC first and plan the requirement of parts. However, we observed that only few groups chose to sketch before starting to make the RC. Prior to students making the models, facilitators had demonstrated two different approaches of building a roller coaster. First, making the path with various parts and later give support with pillars and second, start with building a skeleton structure with pillars only and later add tracks to design the RC. The students had the freedom to choose either option as their approach for designing and execution. Most groups began with the second approach but moved on to using a combination of both methods. One of the major constraints that seemed to influence students' design approach was being aware of the limited time in hand. As a result, most of the teams (G1, G2, G3, G6, G8, G9, G10, G11, G12) simultaneously started making a minimum set of pillars, straight tracks and at least one L-shaped track. Only G5 approached the design task with one task at a time, that is, all members made pillars first, followed by making tracks. Once the teams made a few parts ready for use, tasks were distributed amongst members to assemble the RC model. Estimating the number of pillars they would require to build the RC was important and team members spent considerable time making pillars accurately. Making the paper folds especially the loops required skill and teamwork. It involved careful measurement, accurate cutting, folding and sticking the folds together to form a loop. The entire exercise of measuring and joining of parts was essential in holding the entire weight of the RC. Most groups wanted to make their RC such that it would to be able to hold the marble for the longest time. But they struggled with ways to make time extenders. With constant explorations and testing, they were able to overcome these challenges and came up with a variety of ways to extend the time spent by the marble on the RC. Irrespective of the approaches used, we observed that all groups managed to successfully complete the task within the stipulated time (3.5 hours).

The use of sketches: In design research, sketching has been reported to play a crucial role in generating, developing and communicating ideas (Goel, 1995). However, children may not consider sketching as useful as it is considered by design professionals (Rogers, 1998) and children may shift to exploring 3-dimensional modelling for prototyping and ideation (Welch, 1998; Rowell, 2002; Hope, 2005). Our observations align with the aforementioned. It seemed that the initial use of 2-dimensional sketches for the RC model was not necessary for children; as some groups (G1, G3, G7, G8, G10, G11) retained only a few parts (like the start and end) from their sketch in the final models. Interestingly, we observed G3 sketched and planned on the base provided to them, in addition to a rough sketch on paper. They marked positions for pillars on the box, estimated the number of pillars required and then started making pillars. Two groups (G9, G12) reported that their final model was completely different from their initial sketch. It is evident from their sketches and respective models that none of final models was the same as the initial design sketch. Our observations indicate that in this making task, students preferred 3-dimensional modelling over sketching for thinking, planning, communicating and developing design ideas.

Design exploration and negotiating challenges: Research studies performed with practising designers have shown frequent use of mock-up models and rapid prototyping aids in early identification of design issues, discovering opportunities, conceptual design and eliminating less promising solutions (Hess & Summers 2013; Deininger et al., 2017). Children can also use prototypes as thinking aids for both refining their models and developing design ideas (Yrjönsuuri et. al, 2019). As the students built their RC models, they explored design possibilities, discovered issues with their initial designs and invented novel solutions sometimes through trial-and-error and material manipulations. During the modelling process, they encountered several challenges, such as placement and joining of the parts. At times, the marble would get stuck or would not jump from one track to the other as estimated or it would derail from the track due to excess speed. Through continual revision and testing, however, students were able to evaluate and resolve these problems. Groups spent a considerable amount of time to figure out the size, placement and adaptability of parts such as loops and tracks on the RC model. The procedure to make a funnel or a wide loop had not been demonstrated by the facilitators in workshop 1 (W1). Hence, it was not a part of initial design sketches in any of the groups who participated in W1. But as they progressed with making RCs many students insisted on having funnels and wide loops in their RC model (which they had seen in the demo model). Thus, G10 had initially planned to put one wide loop, instead they placed an S-shaped loop made by combining two wide loops. For G12, the marble did not move through the RC track and got stuck in between. They often had to make adjustments in positioning of pillars, in the wide loop (they had to remove and again stick it properly) to maintain a smooth flow of marble. Therefore, children constantly used their models for exploration, design ideation and evaluation.

Regarding the various technical and design hurdles that students faced, we observed that for the most part students were able to resolve these by themselves without the facilitator's intervention. Students were actively engaged in the task and skilfully made all the different tracks and carefully placed them on the base provided. An example where students did approach the facilitators is described in the case of G3. A boy from G3 showed one of the facilitators a curved loop that the group made and inquired, "I*f I put the marble on this normal loop, then it falls… so, how should I make it (the loop)?*". This inquiry could be a result of knowing the possibility of another type of loop (a wide-loop, which was shown in the demonstrated models designed by the facilitators, but was not taught to students in W1) and the inability to make the same. Here, the process of making, testing, evaluating and not being able to achieve what was desired, made the team members seek our guidance and look for other options. Overall, wide-loop was found to be one of the most difficult parts to make by the students in both the workshops. While making the wide-loop, students got confused between the wall and base of the track and often ended up making a regular loop (U or C shaped) instead of a wide loop (G2, G3, G5, G8, G10). It is only when they tried to stick it to their RC structure, they found mistakes in the making of the wide loop.

G3 also faced a technical glitch and the group members proposed and discussed potential solutions to address it (Figure 1 and Transcript 1 below from field notes). Interestingly, the group discovered that lack of smooth rolling worked in their advantage by increasing the time the marble spent on the track.

Boy 1: The marble is not rolling smoothly from here (gestures by pointing at a location) to here (gestures by pointing at another location).
Girl: Shall we increase the height of this pillar?
Boy 2: But we have already stuck the pillar.
Girl: We need to somehow give it a lift here (pointing at the blue corner)
Boy 3: We can't add pillar here (gesturing at blue corner). [this could be since the design brief insisted on restricting the RC model to the base provided].
Girl: Ok, let's first finish this part (gesturing the track ahead of their problem) and come back to this.

Transcript 1: Adapted from Field Notes.

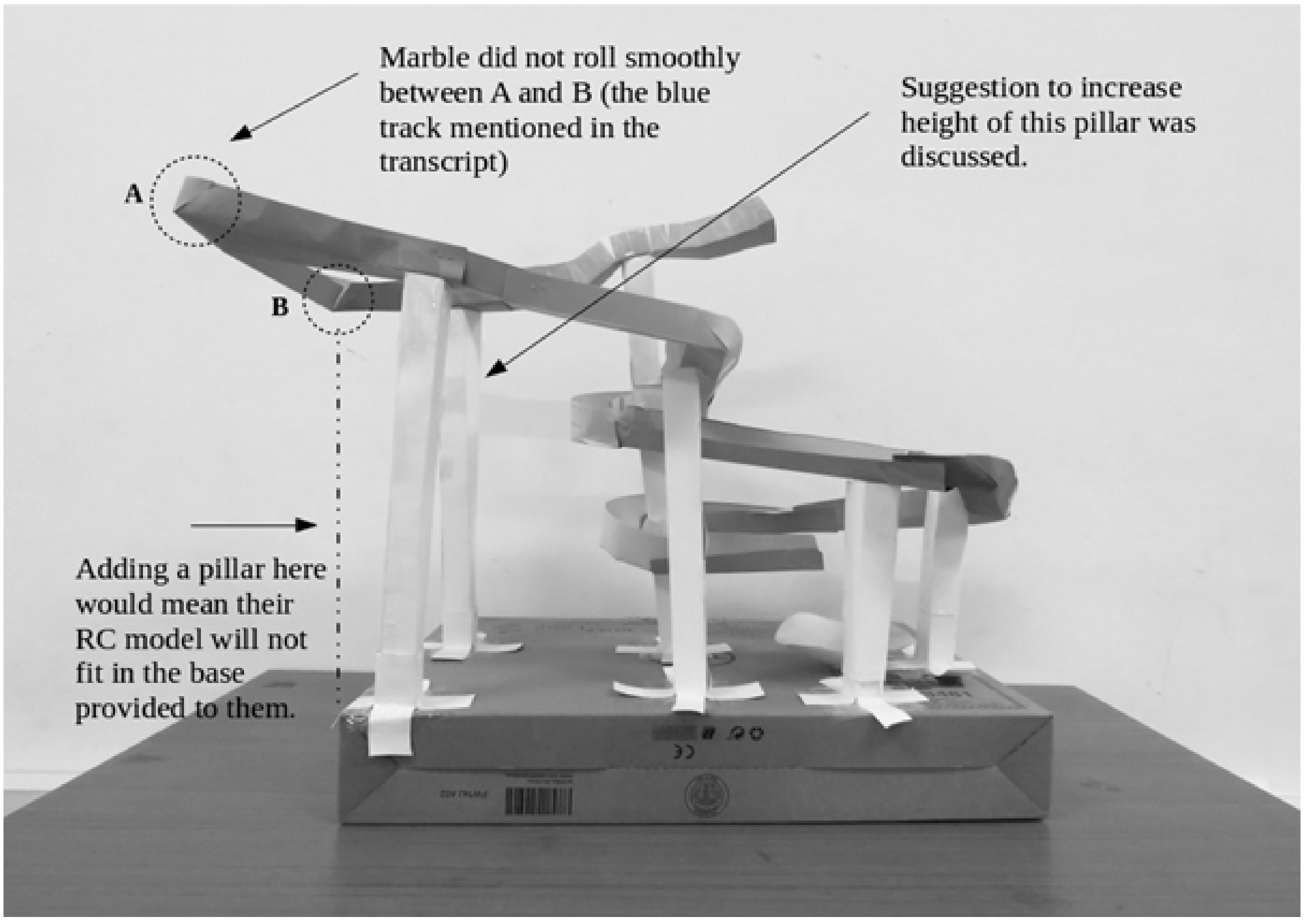

Figure 1: Roller coaster model of G3

Elements of novelty: Within the context of this workshop and our analysis, student explorations and design ideas were considered ‘novel’ if the ideas were unique (design and use of new elements which was not demonstrated by the facilitators) within the group of participating students i.e. ‘local novelty’. Students brought in various novel elements in their RC model under different circumstances. For example, G1 realised they had missed one of the design brief requirements in the RC, a loop. Rather than redoing or moulding the entire RC, they added an innovative element in their design; a disconnected stand-alone half-arc to capture the marble towards the end. The force with which the marble would fall there, would make it go up the arc for a few centimetres, thus decelerating and then the marble would roll back down the arc into the funnel. This, according to the students, added approximately 1.5 seconds to the time spent by the marble on the RC. Another incidence involved G3 realising that their model had a flaw (see Transcript and Figure 1) in one of the tracks, which they later intentionally retained because it increased the time considerably, the marble spent on the RC. Additionally, G3 also explored making a different type of a pillar, in which they inserted one pillar into the other so as to make it adjustable as per the requirements but decided against using it.

More instances of novel elements include; G7 experimenting with a unique use of the pillar structure to drop the marble and make it an interesting starting point. The 'uniqueness' entailed using a pillar as a track. They also made a few hexagonal pillars, and used a track to strengthen another track. G6 made an extended flap which would capture the marble in a compartment. G10 had included a triangular pillar in their model. Some groups also made multiple wide loops (G8, G9, G11, G12) that increased time or introduced twists around the pillar which led to adding levels in the RC. Some models were designed to have intentional breaks in the tracks leading to the marble dropping onto another part (G1, G10, G11, G12). Groups G5, G6, G7 and G9 made RCs which they thought may not keep the marble on for long. Hence, they generated ideas on time extenders and made a variety of speed-breakers (G5, G9), flaps (G9) and multiple staircases (G5, G7, G9). We also saw time extenders being used by other groups (G2, G10). Interestingly, students in G5 and G6 decorated the RC base with the remaining coloured pieces of paper which according to them, added to the aesthetics.

Modelling and collaborative designing: During collaborative designing, design ideas become visible for joint evaluation and development through materialisation and model making (Ramduny-Ellis, Dix, Evans, Hare, & Gill, 2010). Prototyping can be used as an effective method to externalise ideas that might otherwise be difficult to imagine, explicate and verbalise (Yrjönsuuri et. al, 2019). In this section, we showcase instances of how a shared goal of co-creating an RC model encouraged collaboration between group members through material handling, and making and assembling parts of the RC model. In this section, we elaborate on two important aspects of collaborative designing. One was the distribution of tasks and responsibilities and the second was the use of verbal and non-verbal modes of communication. The task of making a working RC in a group within time constraints and the material manipulation and assembling required a lot of coordination and teamwork. Lahti, Kangas, Koponen, and Seitamaa-Hakkarainen (2016) have reported link-ages between model making and materials with division of labour. Particularly, we observed instances where a student was involved in a making task, and either requested help or was offered help to achieve the task (G5, G11). In most of the groups, leaders emerged implicitly or explicitly, and delegated responsibilities, built a consensus among team members and steered the group closer to their final design.

Figure 2: Left- The girl gestures to her group members, the ideal height of the second pillar (G6); Right- Students move the free-track up and down to check for the right incline, before sticking it to the pillar (G11).

The RC model-making acted as a central point of focus which facilitated and mediated discussions through the use of verbal and non-verbal modes of communication. Härkki, Hakkarainen and Seitamaa-Hakkarainen (2018) have noted co-working on building models helps in verbalising ideas, and the role of non-verbal modes of communication, such as sketches and gestures does so as well. They emphasised that gestures play a dynamic role in creating and shaping design ideas leading to further refinement of design ideas. There were numerous instances during the stages of planning, making and presenting, where students resorted to a variety of non-verbal modes of communication, mainly in the form of gestures to propose solutions and communicate problems (Figure 2). Students also used gestures to convey emotions of excitement or disappointment when their model 'worked' or did not.

DISCUSSION

Though the idea of making paper RCs is not new to educators, one has not seen it in practice in Indian settings nor has this been documented. These workshops offered a glimpse of how such a D&T activity can be planned for a class size of around 30, for a time period of around 3.5 hours. Students engaged in open-ended design problem solving which led to the creation of a working model of RC. All groups successfully fulfilled the requirements mentioned in the design brief by acquiring and strategically using paper folding and modelling skills. In fact, no two models were the same and all the models could hold the marble for more than 5 seconds. Our observations revealed that students used a combination of approaches when constructing the RC and did not adhere to their initial sketches much. They preferred 3D modelling over 2D sketches to ideate and communicate. This is perhaps a difference between the way professional designers and school students approach a design problem. More opportunities thus may be built into the structure of the workshop allowing for material exploration and manipulation.

Previous studies have indicated that students often refine their design over the course of planning and making (Khunyakari, Mehrotra, Natarajan, & Chunawala, 2006). Our observations also indicated that students extensively explored various design options while making and testing, negotiated and overcame challenges, and brought in novel elements to their RC model. Lastly, the challenge of model making, and group work resulted in students using verbal and non-verbal modes of communication, which aid collaboration (Jeong & Chi, 1999; Mehrotra, 2008). When students perform such open-ended activities, it helps them: in constructive investigation, to overcome their preconceived notions, to accept and assess mistakes and to rethink or rework on ideas. Though preliminary, the analysis provides insights into planning design problem-solving activities for school students. Observations from this study can also be useful for teachers who wish to implement exploration-based making activities in schools. The work can be extended to understand if and how students reflect on the process of designing and arrive at generalist conclusions about factors that worked in their successful completion of the task.

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Notes

https://www.sciencebuddies.org/stem-activities/paper-roller-coaster?from=YouTube

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Strand 3

Language, Pedagogy and Curriculum in STME

EXAMINING THE ROLE OF COVARIATIONAL REASONING IN DEVELOPING STUDENTS' UNDERSTANDING OF THE GREENHOUSE EFFECT

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Climate change is a pressing issue of the present age. Most of the important information about climate change in the news and public media is in the form of data and graphs, however students often focus on the shape of a graph, overlooking the covariational relationship between the represented quantities. Building on the framework of covariational reasoning, we designed two simulations in NetLogo in which students investigated the relationships between different covarying quantities underlying the phenomenon of the greenhouse effect. In this paper, we present the analysis of two cycles of whole-class design experiments in two sixth-grade classrooms. We discuss the development of students' covariational reasoning as they engaged with the simulations and how this type of reasoning helped them develop their critical thinking about the greenhouse effect.

PURPOSE OF THE STUDY

In the 1992 Earth Summit in Rio de Janeiro, the United Nations Framework Convention on Climate Change (UNFCCC) defined climate change as the "change of climate which is attributed directly or indirectly to human activity" (Kolbert, 2006, p. 153). Indeed, the increasing human population has maintained its dominance over the earth's ecosystem (Karl & Trenberth, 2003). From large-scale burning of fossil fuels (Dolman & Verhagen, 2003) to choosing hazardous household items (Black & Cherrier, 2010), human activities have enhanced the global greenhouse gas emission rate by .5 to 1% every year (Karl & Trenberth, 2003). If this trend of greenhouse gas emission continues, then global temperature might rise between 2 to 5-degrees Celsius in next few decades (Boyes, Chuckran, & Stanisstreet, 1993), which in turn would melt polar ice caps and rise the sea level. To restrain the pace of the existing climatic disruption, though the governments and different organizations have taken a number of initiatives, such as "The Paris Agreement", research shows that introduction of climatic issues in school curriculum would develop within students an awareness about the climate (Shepardson, Niyogi, Choi, and Charusombat, 2009). Mathematics education inarguably plays a significant role in the process of educating students about the complex yet pressing issues related to climate (Barwell, 2013). Consequently, in this study, we aimed to explore the power of mathematical reasoning for developing students' understanding of the greenhouse effect, a major cause behind climate change and help them identify their contribution to the problem.

CLIMATE CHANGE AND MATHEMATICS LITERACY

Climate change and mathematics are closely related. Mathematics serves as an essential tool in every phase of describing, predicting, and communicating the effects of climate change. Governments and policymakers develop laws and policies around environmental conservation, largely based on the predictions made by mathematical models of climate Barwell (2013). Acknowledging the role of mathematics for addressing climate change, Abtahi, Gotze, Steffensen, Hauge, and Barwell (2017) questioned the "ethical and moral responsibilities" (p. 2) of mathematics educators to educate their students about climate. They argued, if teachers assume their ethical responsibilities and incorporate climate change into their mathematics instruction, then that would facilitate students' ability to identify the role of mathematics in climate change and prepare future decision makers to affect change for the betterment of the climate.

THEORETICAL FRAMEWORK

According to Barwell (2013), mathematics literacy is essential for students to interpret data and graphs about the greenhouse effect, as available in news and public media. Consistent with that argument, this study focused on students' covariational reasoning as a fundamental concept for interpreting graphs (Moore, Paoletti, Stevens & Hobson (2016). Covariational reasoning involves coordinating two quantities as the values of those quantities change (Confrey & Smith, 1995). A student reasons covariationally when she envisions two quantities varying simultaneously (Thompson & Carlson, 2017). For instance, a students' articulation, as the amount of carbon-dioxide increases, the air temperature increases simultaneously, illustrates her covariational reasoning. While investigating students' covariational reasoning, Carlson, Jacobs, Coe, Larsen, and Hsu (2002) developed a framework describing five mental actions that characterizes students' covariational reasoning when engaged in graphical activities. According to Carlson et al. (2002), students exhibit first mental action (MA1) when they focus on the coordination of two quantities (For example, carbon-dioxide changes, air temperature changes). Under MA2, students focus on the direction of change of two quantities and reason, as the amount of carbon-dioxide increases, air temperature increases. Mental Action 3 (MA3) involves the coordination between the amount of change in one quantity due to change in the other quantity. For example, students identify, as the value of carbon-dioxide increases by 100 units, air temperature increases by 5 degree Celsius. Students exhibit MA4 and MA5 if they can coordinate the average and instantaneous rate of change of one quantity with respect to change in the other quantity. We used this framework of mental actions to engineer learning opportunities for students to reason covariationally and study how this type of reasoning may create scope for students in advancing their understanding of the greenhouse effect. More specifically, we explored: How may students' covariational reasoning help them develop an awareness about the causes and consequences of the greenhouse effect?

METHOD

The primary methodology of this study is whole-class design experiment (Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003). This highly interventionist method was chosen to engineer particular forms of covariational reasoning and examine the impact of those forms on developing students' understanding of the greenhouse effect (Basu & Panorkou, 2019). More specifically, we undertook the following three primary objectives: a) develop dynamic mathematical activities and implement in middle school classrooms; b) study students' thinking as they engage with the activities and observe the progression of their covariational reasoning; and c) examine the role of covariational reasoning in developing students' understanding of the greenhouse effect. We made a humble conjecture that the dynamic activities would provide students an exploratory space to engage in covariational reasoning, which in turn would help students develop their understanding of the causes and consequences of the greenhouse effect. The activities went through two iterations of implementation and revision (Cobb et al., 2003) to ensure an extent of generalizability.

The Role of Technology in Task Design

Akgun (2013) stated that technology nurtures within students an affinity for STEM literacy and make learning more meaningful and efficient through active participation and social interaction. Indeed, when students are introduced to a dynamic interactive environment through technology, they are motivated to play and tinker with the different features of the interface and engage in learning of mathematical concepts through observation and self-exploration (Resnick, 2014). Prior research on covariational reasoning shows that technology helps students envision the change in quantities as well as to reverse change, which is not always practical with physical manipulations (Castillo-Garsow, Johnson, & Moore, 2013). Consistently, in this study, we used NetLogo (Wilensky, 1999), a multi-agent programmable modeling environment, to develop three simulations on the greenhouse effect. We hypothesized that the dynamic environment of NetLogo, its animated outputs, and the result plots would help students understand the dynamics of the interaction between the different quantities included in the simulations (Basu & Panorkou, 2019). This paper specifically focuses on two simulations, the Climate Change and the Carbon Calculator. We hoped that the simulations would engage students in covariational reasoning and help them understand the causes and consequences of the greenhouse effect. The simulations were accompanied with a set of tasks and questions that we anticipated would provide students explicit and implicit prompts to engage them in critical thinking and shape their cognition (Boaler & Brodie, 2004).

Simulation 1: Climate Change

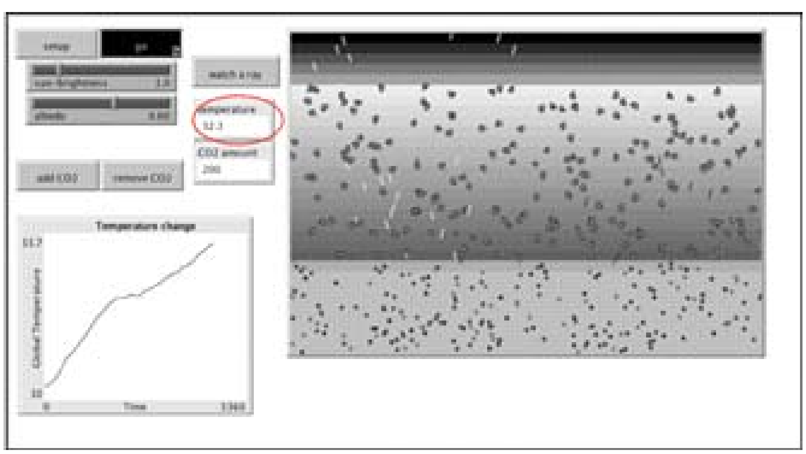


Figure 1: Climate Change Simulation

The first simulation of this study, the Climate Change (Figure 1), is adapted from NetLogo (https://ccl.northwestern.edu/netlogo/models/ClimateChange). This dynamic simulation is a model of the heat energy flow in the earth which provides users a space to explore how two environmental factors, the albedo of the earth and the amount of carbon-dioxide might impact global temperature. Users can move the albedo slider from left to right to change its value between zero and one and observe its impact on air temperature. The simulation also contains Add CO_2 and Remove CO_2 buttons, which the users can use to increase and decrease the amount of carbon-dioxide molecules (represented by green dots in Figure 1) and investigate how the value of global temperature changes along with it. Users can read the value of global temperature as recorded in a temperature monitor on the upper left side of the simulation (highlighted by red color); or they can observe a time-series graph on the lower left side of the simulation representing the change in global temperature with respect to time.

Simulation 2: Carbon Calculator

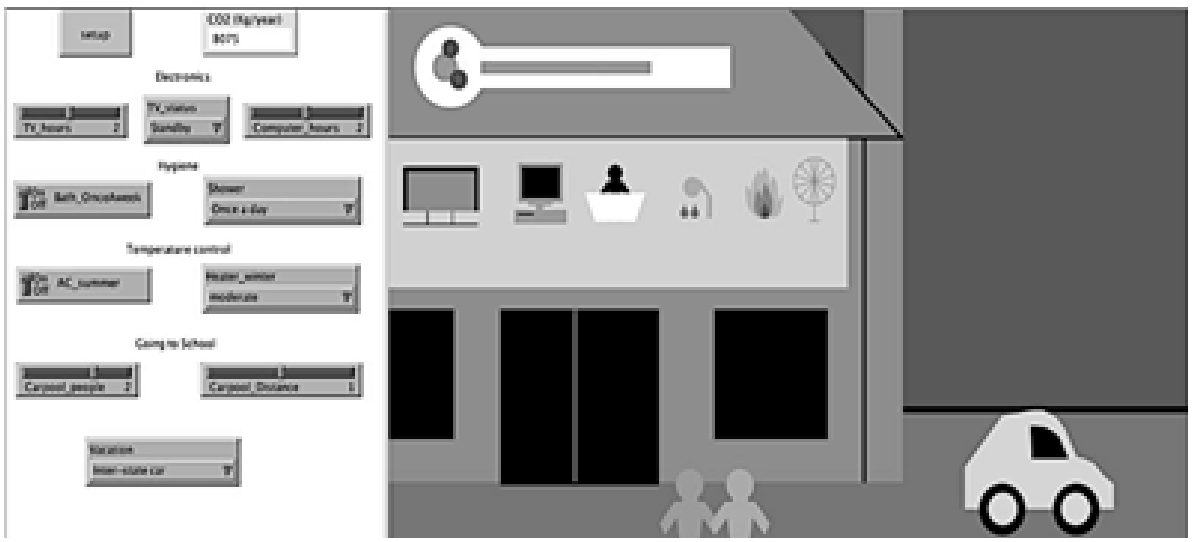


Figure 2: Carbon Calculator

Research suggests that if individuals identify various sources of carbon-dioxide and can estimate their contributions to the issue, then that would lead them to change their own behavior and work towards mitigation of the problem (Padgett, Steinemann, Clarke, & Vandenbergh, 2008). With a similar goal in mind, we designed the Carbon Calculator simulation (Figure 2). The simulation contained several activities, such as watching TV, playing video games, and using air conditioners, that we assumed would be familiar to the students, and are some of the factors responsible for enhanced carbon-dioxide concentration in the atmosphere. The simulation allowed the students to manipulate the values of these factors and observe the impact of the change on annual carbon-dioxide discharge. For example, students could drag the TV_hours slide to the right and left to increase and decrease the total number of TV_hours between zero and four and check the corresponding value of carbon-dioxide in the CO_2 (Kg/year) output box. Likewise, the simulation contained a drop-down menu for shower, that allowed the students to choose the number of times they take a shower in a week and calculate the annual amount of carbon-dioxide released.

Participants and Research Settings

We collaborated with two sixth-grade teachers, Doug and Chelsea (pseudonyms) from North-Eastern region of the United States. We implemented the dynamic activities in their classrooms through two cycles of design experiment. The first cycle took place in Doug's science classroom containing 27 students, and the second cycle took place in Chelsea's mathematics classroom containing 17 students. While Doug and Chelsea conducted the whole-class instruction, a member of the research team interacted with a small group of students to "create a small-scale version of the learning ecology so that it can be studied in depth and detail" (Cobb et al., 2003, p. 9). All the sessions were audio- and video-recorded, and students' written artifacts were collected as a complementary data source. We conducted two stages of data analysis, ongoing data analysis (Cobb, Stephan, McClain, & Gravemeijer, 2001) and retrospective analysis (Cobb et al., 2003). The ongoing analysis, conducted at the end of every session, informed us about students' covariational reasoning and helped us revise the tasks accordingly. Retrospective analysis, on the other hand, guided us to develop more robust theories about students' covariational reasoning that we anticipate might have formed as a result of their interaction with the simulations.

RESULTS

From the retrospective analysis we identified students' reasoning about three sets of quantities a) carbon-dioxide and air temperature b) TV_hours and carbon-dioxide, and c) carpool people and carbon-dioxide. In the following sub-sections, we discuss the forms of covariational reasoning students exhibited as they expressed these relationships and discuss how these forms of reasoning helped them develop an awareness about the greenhouse effect.

Relationship Between Carbon-dioxide and Air Temperature

The session began with students exploring the Climate Change simulation. Students focused on the covariational relationship between carbon-dioxide and air temperature. As students explored the relationship between the two quantities, we asked the them, "what will happen if I increase carbon-dioxide?" In response Nia said, "it increases the temperature." Aiming to examine how Nia identified the increase of temperature, we asked her, "how do you know it is increasing?" Nia pointed to the increasing time graph (Figure 1, lower left corner) in the simulation and identified that if carbon-dioxide increases, temperature gets higher.

Next, students engaged in a graphing activity. We anticipated that the graph might prompt students to focus on the numerical values of the two quantities, thus allowing them to recognize the amount of change and rate of change of air temperature with the change in carbon-dioxide (MA3, MA4). Students plotted the carbon-dioxide and air temperature ordered pairs and graphed the relationship between the two quantities. When we asked them to explain the graph, Ani measured the 'space' between two consecutive values of air temperature in the graph and argued, "this one from here (interval B) has more space than this one from here (interval A). This one has more space in between of them (interval B)." (Figure 3). Referring to the air temperature intervals he further added, "here from here, like 3 fingers and from here to here like 4 fingers. So, it has more space here than here."

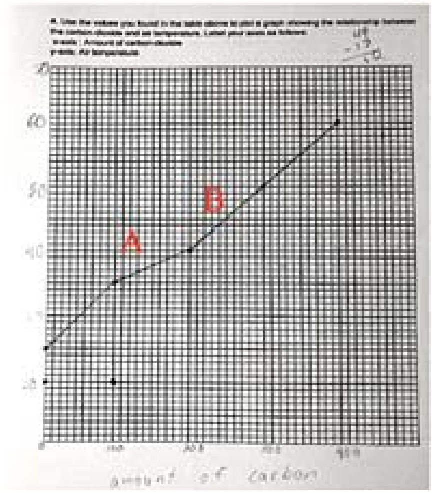
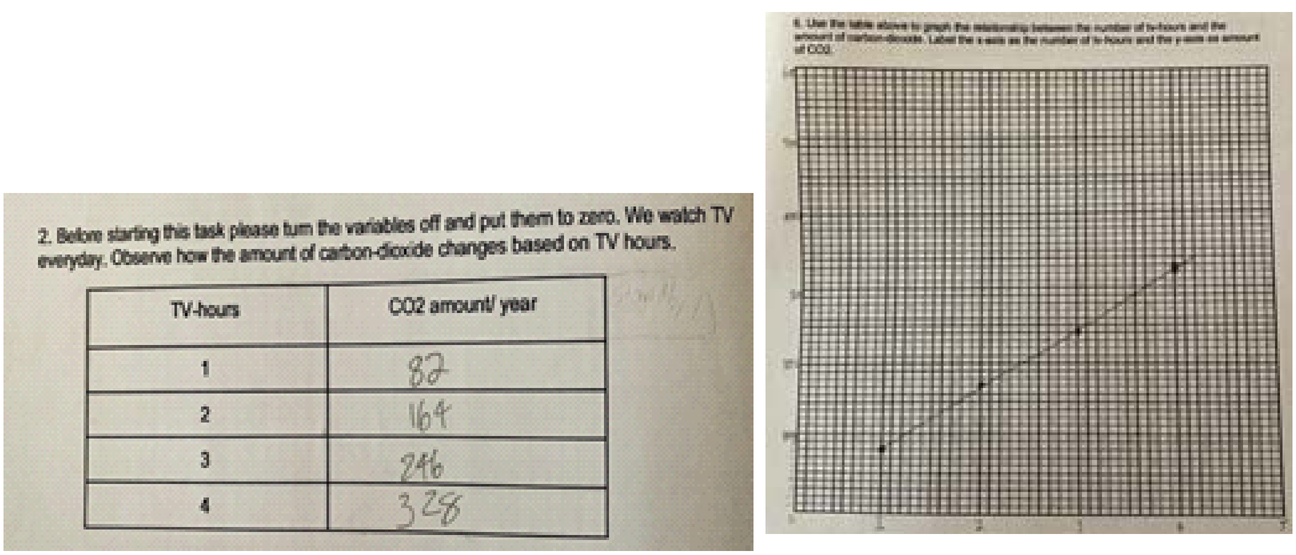


Figure 3: Ani's graph representing the relationship between carbon-dioxide and air temperature

By measuring the space between the various intervals, Ani seemed to focus on the change of value of air temperature in each interval of carbon-dioxide ([0-100], [100-200], and so on). Ani's response indicates that the graphing activity provided him a space to correlate the amount of change of air temperature with change in the value of carbon-dioxide, a type of reasoning aligned to Carlson et al.'s (2002) MA3.

Relationship Between TV-hours and Carbon-dioxide Amount

Next, students worked on the Carbon Calculator simulation. They manipulated the number of hours they watch TV between one and four, observed the corresponding values of carbon-dioxide, and recorded the ordered pairs in the TV hours and CO_2 amount table.



2. Before starting this task please turn the variables off and put them to zero. We watch TV everyday. Observe how the amount of carbon-dioxide changes based on TV hours.

TV-hours	CO2 amount/ year
1	82
2	164
3	246
4	328

Figure 4: Amber's graph expressing the relationship between TV_hours and carbon-dioxide

Students engaged in a graphing activity where they plotted the TV hours versus amount of carbon-dioxide ordered pairs and graphed the covariational relationship between the two quantities. When we asked the students to reflect on the relationship between the two quantities, Amber said that when the TV hours doubles, the amount of carbon-dioxide also doubles. When we asked Amber to explain her response of doubling carbon-dioxide, she added, "You just keep adding depending on the hours of usage of TV." Being unable to understand if Amber was thinking across the two quantities or coordinating the change of one quantity with the change in another, we prompted Amber to explain her answer. She replied,

Amber : *Per hour it is 82. The amount of….*

Interviewer : *Carbon-dioxide?*

Amber : *Yeah. And if you multiply 82 times 2, the total is 164 which is 2 hours. So, for just every hour you just keep adding 82.*

Amber's statement, "So, for just every hour you just keep adding 82" indicates that Amber used the table to focus on the amount of change of carbon-dioxide for every hour change of TV usage and incremented the carbon-dioxide amount by 82 for each unit increment of TV hours. The above discussion suggests Amber's MA3 reasoning.

Relationship Between Carpooling and Carbon-dioxide Amount

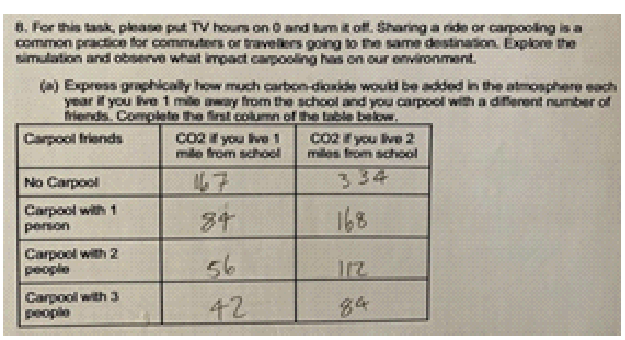
Another activity in the Carbon Calculator simulation asked the students to explore the covariational relationship between the number of people carpooling and the amount of carbon-dioxide being released. Like the TV_hour activity, here as well students modified the number of people carpooling by dragging the carpool_people slider and recorded the corresponding values of carbon-dioxide in a carpooling versus CO_2 table (Figure 5). Next, students plotted the ordered pairs and graph the relationship between the two quantities. However, before drawing the graph, we asked them to predict the nature of the graph. The following excerpt illustrates our conversation with Amber on this regard.

Interviewer : *Before plotting can you give me some idea how the graph will look like?*

Amber : *It will start going down, decreasing.*

Interviewer : *Why?*

Amber : *Because since you are carpooling, the more people you carpool, the less cars you use. So, that means the less carbon-dioxide you are using.*


8. For this task, please put TV hours on 0 and turn it off. Sharing a ride or carpooling is a common practice for commuters or travellers going to the same destination. Explore the simulation and observe what impact carpooling has on our environment.

(a) Express graphically how much carbon-dioxide would be added in the atmosphere each year if you live 1 mile away from the school and you carpool with a different number of friends. Complete the first column of the table below.

Carpool friends	CO2 if you live 1 mile from school	CO2 if you live 2 miles from school
No Carpool	167	334
Carpool with 1 person	84	168
Carpool with 2 people	56	112
Carpool with 3 people	42	84

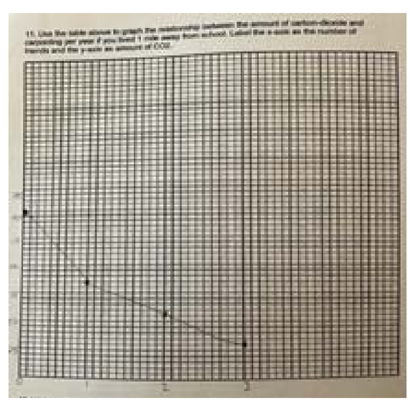


Figure 5: Amber's graph expressing the relationship between carpooling and carbon-dioxide

Amber focused on the directional relationship between the two quantities and identified the greater number of people carpool, the lesser would be the number of cars, and as a result, the reduced would be the amount of emitted carbon-dioxide (MA2).

The activities stimulated a discussion in the classroom regarding the causes and consequences of carbon-dioxide emission. Gio said, “I did not think even if the TV is plugged in or the video game or X-box is plugged in it still releases CO2.” When we asked the students to propose some strategies to lower atmospheric carbon-dioxide emission, Ani suggested that all students need to “talk to their parents not to use cars so much.” He recommended: “stop driving, more walking, using bicycles.” Echoing Ani, Gio suggested using “public transport” to reduce the carbon-dioxide concentration in the atmosphere. From the students’ response it seemed to us that the activities acted as a pre-cursor towards developing their sense of agency towards mitigating carbon-dioxide emission by adjusting their daily practices.

DISCUSSION

Our research has revealed that dynamic mathematical activities allowed students to engage in different levels of covariational reasoning and identify the relationship between quantities expressed graphically (for example, as carbon-dioxide increases, temperature increases), and interpret those relationship in light of the context of the greenhouse effect (excess carbon-dioxide enhances air temperature). Observed trends suggest that covariational reasoning, as illustrated by the students’ excerpts, bridged the mathematical and scientific aspects of the greenhouse effect and helped students develop an integrated understanding of the phenomenon. We expect that this article will leave mathematics and science teachers with afterthoughts regarding their roles and responsibilities in empowering students mathematically and scientifically and helping future citizens to become more sensitive towards their environment.

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DIGITAL COLLABORATIVE ENVIRONMENTS: CONNECTING THEORY OF INSCRIPTIONS TO THE DESIGN AND DEVELOPMENT OF STUDENT RESOURCES

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The paper aims to report on research efforts to design and develop digital collaborative environments for middle grade students (11-13 years old) in mathematics classrooms. Specifically, we report on how a theory of inscriptions can be useful for developing student resources to promote student learning of mathematics. The report focuses on the emerging entailments of constructing and sharing inscriptions as it relates to student's real-time collaboration in a digital platform.

INTRODUCTION

A situative perspective of learning (Cobb, 2002) shifts attention from focusing on representations of the individual mind towards viewing representations as a social practice. Representing activities are "part of networks of social practices that take their characteristic shape and meaning from the contexts, purposes, and functions of their use" (Roth & McGinn, 1998, p. 46). The term, inscriptions, refers to material representations of one's thinking on paper or on the computer screen that are embedded in the networks of social practices. Examples of inscriptions may include text, graphical displays, tables, equations, diagrams, maps, and charts. 'Inscriptional practices' is one of the important disciplinary practices in mathematics (Kindfield & Gabella,2010) and refers to the use of inscriptions for productive behaviors such as expressing, interpreting, explaining, predicting, critiquing , reasoning, exemplifying, and communicating mathematical and scientific ideas (Wu & Krajcik, 2006). Understanding of inscriptions and inscriptional practices are powerful because they can be used not only for analytic purposes but also for designing educational environments and curriculum materials. The latest technological advancement and digital pedagogical innovation allow for additional affordances of constructing, sharing, and using inscriptions. These affordances can potentially enhance the 'inscriptional practices' and help in mathematical sense-making. In this paper, we highlight how student digital resources are designed and developed for encouraging real-time collaborative construction and sharing of inscriptions in a middle school (with 11-13 years old students), inquiry-based math classroom.

INSCRIPTIONS, INSCRIPTIONAL PRACTICES AND ITS IMPORTANCE IN COLLABORATIVE MATHEMATICS LEARNING

Inscriptions are powerful for collaborative learning because knowledge-construction takes place at the individual as well as the group level and students develop and use practices that emerge over time in a classroom setting (Medina & Suthers, 2013). To support students in the collaborative learning environments, Wu & Krajcik

(2006) found that embedding the use of inscriptions in the inquiry process, providing scaffolds to support inquiry, sequencing tasks, and the inquiry process, and engaging students iteratively in the inquiry process are critical for developing inscriptional practices. Students' individual inventions of inscriptions can be translated and integrated through social interactions into the conventions of the classroom community (Enyedy, 2005).

While inscriptions show promise for developing collaborative learning environments, challenges still remain. Sandoval & Millwood (2005) reported that students typically did not refer to specific features of inscriptions when making a claim, resulting in a limited or vague interpretation of the reference by others. Schnotz and Bannert (2003) observed that inscriptions are only effective when they are appropriate to the task. Bowen and Roth (2002) reported that learning with inscriptions is effective when students are "engaging in activities during which inscriptions are something 'everybody uses' to convince others of the utility and accuracy of their arguments" (p. 324). While most of the research on inscriptions for collaborative learning can be found in the science and technology literature, more research is needed in mathematics education (Cobb, 2002; Roth & McGinn, 1998).

THEORY OF INSCRIPTIONS

Roth and McGinn (1998) describe a theory of inscriptions around representing as a social practice. According to the theory (pp. 37-38), inscriptions have eight common characteristics:

- easily able to be sent and received,
- do not change when being sent or received,
- easily embedded into different contexts,
- easily modified,
- easily combined and superimposed with other inscriptions,
- reproduced at low economic, cognitive, and temporal cost,
- easily merged with geometry, and
- often translated into other inscriptions.

In mathematics, knowing and learning are "situated in social and intellectual communities of practice, and for their mathematical knowledge to be active and useful, individuals must learn to act and reason mathematically in the settings of their practice" (Greeno, 1988, p. 482). Thus, "to be a representationally literate individual means being able to participate in the practices of producing, comprehending, comparing, and critiquing inscriptions" (Roth & McGinn, 1998, p. 45).

RESEARCH GOALS AND METHODS

The research shared in this paper is part of a larger project that aims to study how the use of digital inscriptional resources can improve middle (11-13 years old) school students' mathematical understanding. Towards the goal of improving students' understanding, the larger project makes use of design research (Barab, 2014) to focus on iteratively developing and enacting a digital collaborative math environment.

According to Barab (2014) the goal of design based research is to "use the close study of learning as it unfolds within a naturalistic context that contains theoretically inspired innovations, usually that have passed through multiple iterations, to then develop new theories, artifacts, and practices that can be generalized to other schools and classrooms" (p. 151). In the larger research project, as part of the design research process, classroom data collection, data analysis, and informal and formal feedback from students and teachers using different methodologies inform subsequent iterations of development and enactment. Data sources include student and teacher interviews, student and teacher surveys, classroom video, computer screen recordings, student and teacher audio recordings, and copies of classroom artifacts. While examples of this development and research efforts that inform development are reported elsewhere (e.g., Edson, Kursav, & Sharma, 2018), the purpose of this paper is to draw on conjecture mapping (Sandoval, 2014) to show how theoretical perspectives, technology development, and implementation are interconnected. To this end, we will report on the mapping of three important distinctions necessary for testing conjectures in design research: (a) the design of the digital materials through the inscriptional theory perspective, (b) the development of the materials and its embodied features, and (c) a description of the learner's enacted experiences in the classroom. Evidence for these distinctions draws from different sources, including the theoretical and empirical research literature on inscriptional theories, user stories and feedback for iterative development of features, and classroom observations and opportunities afforded by the developed features. Thus, the contribution of this paper is to report, through the context of our design research efforts, on how the affordances of collaborative and dynamic inscriptions can be connected to the theory of inscriptions through digital technologies.

Over the years of the project, the research team worked with approximately 5 teachers and their students from several districts, each year that made use of the Connected Mathematics curriculum materials (Lappan, Phillips, Fey, & Friel, 2014). The Connected Mathematics is a problem-based middle school curriculum used in grades 6-8 in the United States and forms the curricular pillar of our work. The overarching curriculum and pedagogical ideas of this problem-based curriculum inform the design principles of the digital environment. The curriculum has existed in the print medium and we are currently in the process of studying the affordances and limitations of enacting the curriculum in the digital environment. In the curriculum, contextual tasks situations are used as mathematical problems and encourage some or all of the following features: (a) important and useful mathematics is embedded within the problem situation, (b) it stimulates both conceptual and procedural knowledge, (c) connects to and builds upon other core mathematical ideas, (d) warrants higher level thinking, problem-solving and reasoning skills (e.g., mathematical practices),(e) affords multiple entry points and access points into the problem, (f) ensures engagement for the learners and promotes rich mathematical discourse, and (g) creates opportunities for teachers to formatively assess the student learning (Lappan & Philips, 2009).

Figure 1 shows a screenshot of an individual student active in the digital platform developed as part of the design research study. In this digital platform, mathematics problems were (re)designed and presented in a new problem format. The intention behind the new problem-format is to further strengthen the emphasis on inquiry and exploration of mathematical ideas through rich problems, meaningful classroom discourse practices, and increased collaborative problem solving. In particular, the problems are now formatted within three components (a) the *Initial Challenge*, where students are introduced to the context of the problem situation.,(b)

Figure 1: Screenshot of the student working in the individual workspace on the digital platform.

What If…? where students are expected to unpack the embedded mathematics, and (c) *Now What Do You Know?* where students summarize their learning and makes the connection to their prior knowledge and may also highlight the relationship to related upcoming mathematical topics.

The digital platform supports real-time, synchronous collaboration among students, who upon logging into the specific problem are organized into groups of 2-4. Using the inscriptional features on their individual laptops, students can write text, draw figures (using the cursor), make tables, generate graphs, paste screenshots, upload photographs, and use stamps (pre-populated) on their individual workspace. The workplace of an individual student is connected to the workspaces of other students (in their group and also to others in the class). Students can also share their work with other groups by publishing it. Once published the work can also be accessed by students in other groups. In the digital platform, the students can drag and copy the inscriptions embedded into any other workspace into their individual workspace. The other workspace could be - the problem workspace, other students' workspace, and also the teacher's workspace. The *Learning Log* provides a distinct space in the digital platform for students to curate, collect, revise, combine, and revisit inscriptions. The Learning Log is intended as a place for students to record overarching ideas that span across problems, units and even grades. At the teacher's end , the digital platform offers features, such as, (a) assigning individuals to specific groups, (b) accessing student's individual and group workspaces, (b) creating customizable "just in time" prompts that can be directed at individual students, groups, or the class, and (c) presenting selected student's work along with added annotations and also publishing it (and hence sharing it with the class) during whole-class discussions. While most of the inscriptional tools and the collaborative features are common and remain constant across problems, the problem space is customized for each of the problem with specific inscriptional tools (including mathematics-specific tools). The inscriptional resources are hence- carefully selected keeping in mind the mathematical learning goals contributing to creations of inscriptions that relate to the embedded mathematics into the problem. The resulting set of inscriptional and collaboration features in the digital platform hence accord specific mathematical problem-solving capabilities and distinguishes it from other generic collaboration platforms that might be found in other content areas.

The above description of the digital platform makes it easy to see how many of the eight characteristics of inscriptions (like easy transferability, modifiability, remaining unchanged, reproducibility, superimposing and others) identified by Roth and McGinn (1998) are feasible in the context of this digital platform. It is interesting to note that with the innovations introduced in the digital platform, new inscriptional characteristics and affordances have emerged. In the following section, we discuss examples of intended and actual use of the digital platform, by the students, for constructing and sharing inscriptions.

CONSTRUCTING AND SHARING INSCRIPTIONS USING THE REAL-TIME, COLLABORATIVE AND DYNAMIC DIGITAL ENVIRONMENT

As detailed above, the collaborative digital platform forms the design innovation for constructing and sharing inscriptions. Figure 2 shows the screenshot of the laptop screen of the same student as before. The individual screens of the other three group members are also visible to the student. The students are working on a mathematics problem from the seventh-grade unit, *Stretching and Shrinking: Understanding Similarity*. Problem 2.2 Hats Off to the Wumps: Changing a Figure's Size and Location. The overall learning objective of the problem is to help students use scale factors and ratios to describe relationships among the side lengths, perimeters, and areas of similar figures. More specifically students see how some similarity transformations, through changes in the *x*- and/or *y*-coordinate, move the figure (hat) and /or change the size around but preserve its similarity.

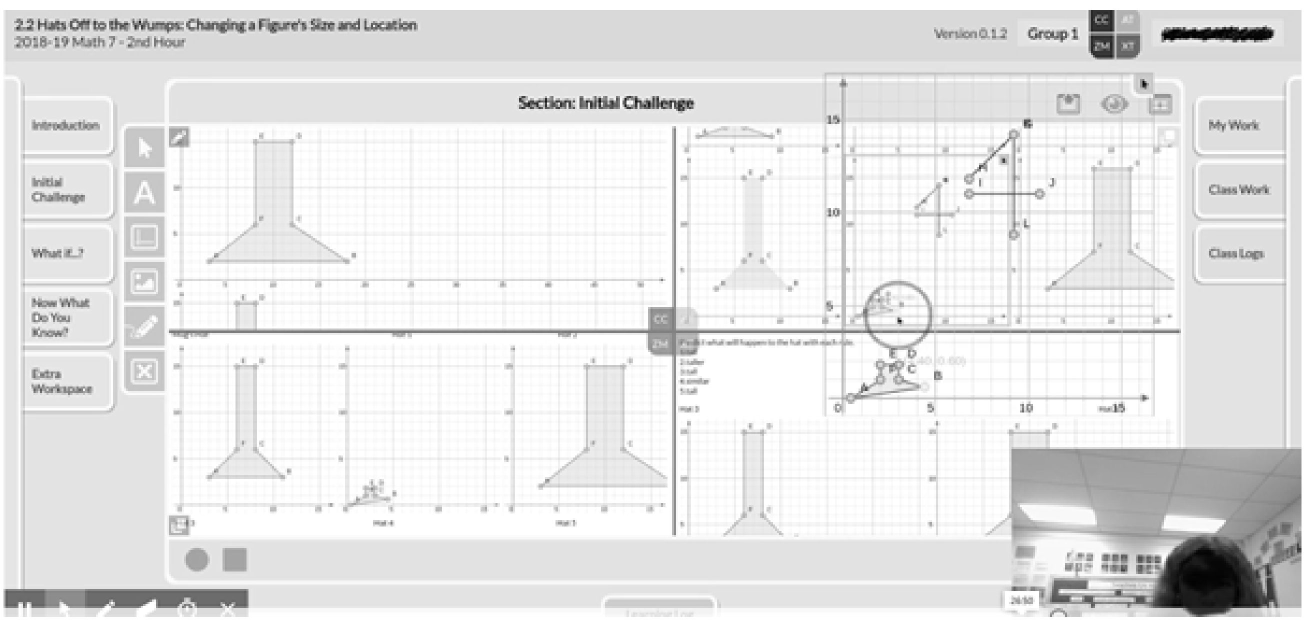

Figure 2: Screenshot of a student collaborating with other group members

We use the context of the problem above to highlight specific examples how students from our research used the digital platform to construct and share inscriptions. Collectively, these examples of the available features and the actual enactment indicate the emerging affordances of inscriptions and highlight the potential to strengthen inscriptional practices using innovative use of technology. To this end, we primarily draw on the data sources of classroom video and computer screen recordings to report on classroom observations that relate to the student use of the digital resources. Other data sources are used to affirm or refute (and subsequently modify) the classroom observations reported in this paper.

Students use of digital platform to construct automatic and dynamic inscriptions

In the digital platform, classroom observations revealed that students can create new inscriptions that build on existing work, which are automatically generated and are dynamically linked across multiple inscriptions. In the above example, students can drag inscriptions (for e.g. the diagram of the hat(s), table containing the transformation rules and coordinates) from any problem component or workspace into their individual workspace without needing to recreate them. The red circle in Figure 2 is the cursor of the student who is trying to drag and embed an inscription from another student's workspace into their individual workspace. Classroom observations revealed that the digital platform not only allows students to collectively populate the coordinates in the table corresponding to the given rules, but it also automatically generates the corresponding figure on the coordinate grid. Classroom observations revealed that the platform also allows the students to hide or make visible any hat and also to move the hats on the coordinate grid as they compare the hats for similarity. The physical movement and laying of a hat over the other hats, opens up additional opportunities for determining similarity (specifically angles). Importantly, as the students attempt moving the hats, the corresponding changes in the rules and coordinates are reflected in the table in real time due to the linked nature of the table and the graphing tool. It was also observed that the instant and dynamically linked nature of the inscriptions enabled the students to test their own rules and map the corresponding movement and / or changes in the hats and vice-versa.

Students use of digital platform to collaboratively share inscriptions

Classroom observations revealed that the digital platform allows students to generate, share, and access inscriptions synchronously and in real-time. For example, in the figure above, by giving permission, any student in the group can allow the other group members to see their individual work in real-time. Also, classroom observations revealed that the publish feature allows the student to post their work which is then accessible to the whole class. Students in a group can work together on a single workspace where each one of them can work on the same (or different) components. As the students have real-time access to each other inscription, the student can compare and contrast the alternative strategies, ask for clarification, revise their own strategies to use alternative/multiple ideas, and practice the metacognitive skill of evaluating and choosing the most appropriate solution strategy. Classroom observations further revealed that the platform also offers easy accessibility, retrievability and reusability of digital inscriptions, and the ability to organize it within the learning log space. As the class reviews and discusses the concepts related to the mathematical goal, specifically using the *Now What Do You Know* prompt, it was observed that the digital platform allows learners to readily embed inscriptions from curriculum materials, problem workspaces, the workspaces of classmates or the teacher, or prior learning log entries into their learning log. In the example above, students can combine and/or edit the inscriptions to reflect their evolving mathematical understanding of similarity, making deeper connections to other concepts and procedures including those from previous problems.

These novel affordances of constructing and sharing inscriptions using the digital platform have implications for the inscriptional practices and mathematical proficiency.

DISCUSSION

The research literature shows that student capacity to represent knowledge and make sense of their inscriptions is essential for conceptual understanding within mathematics (Medina & Suthers, 2013; Cobb, 2002). However, capturing inscriptional construction practices is messy and complicated (Roth & McGinn, 1998), especially in the context of collaborative small group classroom settings. Given the advances in digital technologies, we have new opportunities to utilize inscriptional practices that are “in-the-moment.” Many of the affordances related to the construction of inscriptions detailed above (like instant dragging and copying, constructing collaboratively and in real-time, dynamic interlinking of multiple inscriptions, temporally extending the inscription construction, easy retrievability and combining) are difficult to replicate not only in the paper-pencil context but also through the use of traditional technology tools. The emerging affordances through the use of innovative technology can enable learners to focus their cognitive effort on the important inscriptional competence rather than on the procedural aspects of inscriptions. Thus, these affordances can contribute in helping students make coherent connections among mathematical ideas that otherwise may appear arbitrary and disconnected.

diSessa (2004) foregrounds the importance of “metarepresentational” competencies that go beyond the production and interpretation of inscriptions. These include the competencies to invent or design new inscriptions; to critique and compare the adequacy of different inscriptions; to understand purposes, contexts and the ways in which inscriptions work; explain the inscriptions itself and the connections across inscriptions; and to engage with new inscriptions (Kindfield & Gabella,2010). Using the affordances of collaboratively sharing inscriptions and having real-time access to one another’s problem-solving strategies can promote “metarepresentational” competencies and facilitate collaborative sense making. By making the process of inscriptional construction and sensemaking publicly shared and negotiated among students, the affordances of the digital platform can strengthen the social dimension of the inscriptional practices.

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CHARACTERISING SCHOOL STUDENT DISCOURSE WHEN ENGAGED WITH CONTEMPORARY BIOLOGICAL RESEARCH

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This study involved four groups of six students, aged 16-17, discussing a contemporary biomedical research problem. Drawing on Chinn and Malhotra's (2002) criteria for authentic scientific research we analyze those patterns of talk and use of knowledge which lead to outcomes reflecting authentic science practice. Adapting a coding scheme from primary school science discussions in constructing knowledge we show that fruitful discourse has the following features: authoritative scaffolding encouraging elaboration, explanation and reactualization of school knowledge; willingness of participants to problematize suggestions; collaborative elaboration of ideas sufficient to stimulate new research questions. We advocate the profitability of such research problems to move beyond the constraints of the curriculum to deepen student understanding of research science.

BACKGROUND

In discussing authenticity, Kapon, Laherto and Levrini (2018) refer to a need to "awaken . . . the scientific spirit" and the practice of scientists. Tensions exist, however, from prescription of content at one end to creativity at the other. For example, the tension between "content fidelity" (Kapon et al., 2018) – established knowledge and procedures, contrasted with personal relevance to students as generators of their own knowledge. Another problem, pertinent to the project we discuss below, is that of "language and discursive norms" (Kapon et al., 2018); for example, school students are often assessed on knowledge they have acquired as individuals whereas research discourse reflects collaboration, communicative acts of normative meaning (Derry, 2016). 'Significance' exposes another tension: that between the topics and methods of professional science and solving personal or community-relevant problems.

Chinn and Malhotra (2002) identified significant differences in cognitive and epistemic perspectives between school science inquiry and authentic science research which reflects aspects of authenticity discussed above. These differences, based on Chinn and Malhotra's analysis are listed in Table 1.

Process	Research science	School science
Research questions	Generate or adapt own research question	Research questions provided
Variables	Select variables to investigate out of many possibilities	Investigate and report on prescribed variables
Planning procedures	Invent complex procedures to address questions of interest	Follow simple directions or devise simple procedures with predetermined variables
Controlling variables	Difficult to decide what controls should be or how they should be set up.	Told what variables to control
Finding flaws	Constantly question their own or others results, or artifacts and experimental flaws.	Flaws in experiment rarely salient or assume extrinsic flaws such as doing experiment incorrectly.
Indirect reasoning	Observations related to research questions by chains of inference	Observations directly related to research questions
Generalisations	Need to judge whether to generalise from the experimental situation to other situations.	Only generalise to similar situations.
Types of reasoning	Employ multiple forms of argument	Simple contrastive, inductive or deductive reasoning
Level of theory	Construct theories postulating relevant mechanisms	Either uncover empirical regularities or illustrate theoretical mechanisms

Table 1: Differences between scientific research and school science inquiry

Our research was directed at exploring how students might use their school knowledge when engaging with an open research problem and the types of interactions that might facilitate deeper understanding. Findings that emerge from this research will inform science teaching particularly for those students transitioning from school to university, and also for undergraduate science teaching.

While most investigations on students learning authentic practice has focused on laboratory-based activities, our intention was to draw on the 'elaboration of ideas' behind mechanisms (Abrahams & Millar, 2008), removing the possible distraction of manipulating sophisticated instruments in a laboratory environment.

THEORETICAL FRAMING

In this project we were interested in how knowledge underpinning scientific research, as depicted by Chinn and Malhotra (2002), is constructed through discussion, and what kinds of discursive features enable the production and use of such knowledge. For example, what are the social moves in a discussion which enhance or inhibit productive reasoning about research? What are the differences between addressing a problem within the constraints of the curriculum and one which presents an entirely new arena of thinking? What for school students would constitute acceptable evidence and what means would they use for validating that knowledge? Students were aiming to provide explanations for a biological phenomenon which was new to them. To provide plausible accounts they had both to draw on their pooled prior knowledge and construct new meanings: they were asked to draw on different types of knowledge – academic school knowledge, knowledge of doing experiments, experiential and situated knowledge – to explain why groups of cells in the embryonic spinal cord independently segregate (see Methods for a fuller account of the problem). Gaps arise between what is intelligible and 'stands fast' for the students (Wickman & Ostman, 2002). Discursive encounters between participants, the scientist and representations of the process help to construe new meanings. In this study we view knowledge from a pragmatic perspective in which it is seen as action, something that is done rather than located inside a subject's head. Meaning making takes place where participants in a discussion create connections between prior knowledge and the situation at hand, i.e. 'reactualizing' their knowledge.

The relevance of Wickman and Ostman's paper to our research is that it goes beyond the situational aspects of learning to explain how, on a discursive level, meaning changes in the light of new experiences. Through a pragmatic approach they view learning as a social construction acknowledging the physical world as encountered by with cognitively and emotionally acting and interacting individuals. Our focus is on how prior knowledge changes when students are confronted with new and complex phenomena to make sense of in discussion. Such an awareness of change putatively leads to problematising enaction of scientific concepts and, through dialogic interaction, to building new knowledge where gaps previously existed. Encounters between participants and the 'texts' influence meaning and involve prior knowledge and experiences.

Our research questions are: 1. To what extent does engagement in authentic inquiry enable school students to exhibit salient features of research science? 2. What discursive features enable fruitful moves towards authentic inquiry? 3. How do students use their extant knowledge to address a novel and complex situation in scientific research?

METHOD

We invited four groups of students from three different schools to address a research question which the developmental biologist has been working on for the past 20 years, namely to account as far as they could for the separation of cells through the process of differentiation and specialization in the developing spinal cord. The discussions took place in a room at the university. Six students were apportioned to each group; students in each group were from the same school and were familiar with each other. Three of the groups came from schools in socially disadvantaged areas and were gender-mixed. Participation was entirely voluntary and students were sent a letter explaining the research and opt-in and opt-out options.

The research took place over two separate days and all the discussions were recorded and transcribed. Notes were taken in situ to describe any relevant gestures or writing to complement the transcriptions. Initially, the problem was framed as being one found in all tissues and all animal species and schematized in a figure showing two different cell-types represented by two sets of differently colored spheres.

The spheres were initially shown as randomly intermingled with representation of time being shown as an arrow whereupon the two colored spheres segregate and cluster into two distinct groupings. The pupils were then asked to draw upon their current knowledge across all subject areas to hypothesize how the two different cell-types could segregate and cluster.

The discussion about these slides took the following format. - The scientist presented the problem orally to the students together with a simple model of differently coloured cells asking them to explain how they could account for their separation. They were encouraged to suggest experiments they might carry out to support their explanations together with evidence they would be looking for; they could ask the scientist any question they deemed necessary at any point; a volunteer from the group was to summarize their discussions once they had exhausted explanations, and before the next stage of the process was presented to them. Altogether the slides were presented in a sequence. It is the first two that are relevant to the discussions below. The duration of the discussions was between 70 minutes and 94 minutes.

Coding for the analysis was drawn from Hogan, Nastasi and Pressley (1999) where groups of students, albeit primary school students and under closer teacher guidance, are trying to make sense of incomplete scientific ideas. Our students were similarly working through dialogue towards an end of trying to either establish consensus or at least rational grounds for disagreement around new scientific ideas they were trying to make sense of. We have modified these micro-codes from Hogan, Nastasi & Pressley (1999) to take account of the particular context of this discussion (Table 2).

The dialogic interactions were organized into episodes. An episode comprises an opening statement on a topic which might be in the form of a question, assertion, conjecture, prediction, summary or focus towards a task. Such a statement leads to a response by at least one other person in the group or the research scientist (RS) if he had been called upon, and the focus on the topic then continues for at least one more statement.

The dialogue was then organised into codable units. Four of the researchers shared their codes. Differences between specific codes were negotiated and a new scheme drawn up. This was done three times until there was complete inter-rater agreement. Where conceptual knowledge drawn from the school curriculum was used or mentioned in a sequence this was also noted as were any aspects of research science derived from Chinn and Malhotra's analysis in table 1.

Statement type	**Sub-statement (code)**	**Description**
Initiates	Initiates episode (In-Ep) Initiates idea (In-I) Initiates partial idea (In-PI)	Statement which generates episode. This might be incomplete conceptually but is sufficiently substantive to invite follow up. Statement which specifically directs attention to a possible mechanism Statement which is vague but can be built on towards a mechanism or model.
Elaborates	Self (El-S) Other (El-O)	Participant builds on a previous statement they have made Participant builds on previous statement made by another participant
Clarifies	Self (Cl-S) Other (Cl-O)	Makes clear previous statement participant has made without adding further concepts or ideas. Clarifies statement of another participant without adding further concepts or ideas

Statement type	Sub-statement (code)	Description
Explains	(Ex)	Gives a reason for concept or idea.
Gives evidence	(Ev)	Produces putative evidence for an idea or concept which can be tested. Often in the form of a prediction.
Problematises	(Pb)	Questions the validity of a claim
Reviews	(Rev)	Summarises or reviews what has been said
Question	(Q)	Any statement designed to elicit a response
Response	Neutral response (R-N) Positive evaluation (R+)	Acknowledgement of previous statement of participant without any kind of evaluation Acknowledgement with positive value comment of previous statement
Subject knowledge	(SK)	Where participant draws on conceptual scientific knowledge, usually from school curriculum either explicitly stated or inferred
Metacognitive	M	Participant explains how they are thinking

Table 2: Coding structure

RESULTS

We have drawn on three episodes to illustrate discursive moves which reflect authentic science inquiry. As a significant qualification, these three were the only substantive exchanges which we could depict as episodes. Nonetheless, we argue they comprise dialogic features where collaboration enables students to demonstrate fruitful practice in attempting to close a cognitive gap through the use of knowledge. For reasons of space we only focus on more salient exchanges.

Episode A

For the first seven minutes of the discussion students from Group 1 have been discussing what makes the two types of cells (modeled as orange and green) separate with little progress. In the initial sequences, one of the students, Muna, offers vague suggestions with the Research Scientist (RS) prompting her to elaborate her ideas.

Muna: Would you have to see, because it happens all over the body, so would you have to see any common factors that's linking all of the groupings together? (Q; In-PI)

RS: That's really good, yes. (R+) . . . how would those common things work do you think? (Q)

Muna: . . . not quite sure (M), things like pH levels or iron levels or whatever's going on you can link together and what could attract cells (In-Id; SK).

RS: OK (RN).

At this point, another student in the group, Rabia, makes her first contribution drawing on her school knowledge, offering a specific explanation of cell signalling.

Rabia : So like cell signalling happens with glycoproteins (SK), so maybe then to find signs of glycoproteins in an orange cell or a green cell could help differentiate them (Ex; Ev).

RS : OK (RN). . . .So what is the model that you are making? (Q) How does that make [the cells] separate? (Q)

Rabia : . . . things might like attach to the glycoproteins (Ex) because I'm just like linking back to things that we've done in school, with like antibodies and stuff (SK).

RS : Yeah (RN).

Rabia : So they are specific to certain antigens, so if an antigen, antigens such as proteins, so if they are not found on the green cell then the thing in the body wouldn't be able to attach to the green cell to be able to bring it over to a different area (SK; Ex).

RS : OK (RN).

Rabia : So if there was a mechanism that, like, attached to one of the proteins on the membrane of the orange cell but it wouldn't be able to attach to the green cell, then eventually over time all of the orange cells would end up in one place being attached to those proteins. (Ex; Ev).

In relation to Table 1 two distinct features of authentic research science have been demonstrated: (i) constructing a theory postulating mechanisms; i.e. molecular bodies attached to proteins in the cell membrane, and (ii) Drawing on school science knowledge about antibody-antigen mechanisms to formulate an explanatory model.

Episode B

Episode B follows shortly after Episode A where the group now considers the evidence for Rabia's model. Muna again initiates a tentative suggestion of testing for proteins in the membrane but this suggestion is challenged because they do not know which protein to test for. Don then proposes a control experiment to check if proteins are the material cause of cell separation.

Don : What about if we denature the proteins . . . (P-Id; SK). . . so we heat up the cells and let the proteins denature but the cells don't get destroyed, and then we see, if they still split… (Ev).

Muna : Yeah, that would be good (R+)

Nita : But would it be possible to denature the protein without affecting how the cell works? (Pb)

We have extracted here the central problem identified by Nita that denaturing the protein influences more than one function hence control experiments in scientific research are more complex than those experienced in school science.

In this episode in relation to Table 1, students: find flaws in their experimental design; employ rebuttals in problematising; construct knowledge in groups (they have been able to explain collaboratively why the gap between their explanation and outcome is so problematic.

Episode C

Episode C was taken from the discussions of group 3 just after RS has introduced the second slide (Figure 1B).

Orla	:	That immediately made me think about electrolysis and how they move to one side (In-Ep; SK), so maybe it is kind of like the cells signalling how they are, like it's within them to go and move to the other side (Ex), so then the orange wouldn't have been separated, they'd have just been left behind (Ev).
Group	:	OK (RN)
Carol	:	So it's to do with the green cells (Cl-O) rather than an interaction between the two types of cells. (El-O)
Group	:	Yeah.(RN)

After this every member of the group offers ideas, some of which are refuted, resulting in Katie summarising the different positions and different research questions. (Table 1)

Katie	:	So is the green moving because of something that happens within that environment? or is the green, so is it kind of moving independently of the orange, and has nothing to do with the orange cells, it's to do with the function of the green cell? . . . or the function that the orange cell carries out that stops it performing its function? Or maybe it's evolved because they are similar cells with similar functions? (Q; In-Id).

CONCLUSION

From the coding sequence we can identify three distinct discursive patterns that we denote as (a) Tutor scaffolding from tentative speculation to elaboration of a model (episode A); (b) Student problematization (episode B); (c) Developing research questions (episode C). From episode A, we suggest that the involvement of a science researcher, or a teacher strongly acquainted with the researcher's work, to help scaffold participant questions would enhance authenticity in these interactions. Throughout the discussions, it is possible that gentle scaffolding from the researcher, as seen in episode A, might have resulted in more productive outcomes. On the other hand, there is a difficult line to draw between over-intervention and successful scaffolding.

Problematization is a process of reasoning infrequently encountered in school science, "the work of identifying, articulating, and motivating a problem or clear question" (Phillips, Watkins, & Hammer, D. 2018, p.983). In episode B in particular, problematization generates uncertainty which in the end the students cannot unravel. Encouraging students to problematize requires considerable pedagogic skill: to anticipate the uncertainty, to demonstrate in this case that control experiments in complex systems require a deep knowledge of the system, and aiding the formulation of possible solutions which help students appreciate the gap between simple procedures in school science and the complexity when working on open-ended problems. Finally, in episode C a participant draws on school knowledge to propose an analogy which through a series of clarifications and elaborations results in two participants proposing a range of research questions.

The evidence suggests that when pre-university students with sufficient background knowledge are given the opportunity to discuss research problems with a research scientist, these discussions approach authenticity, and knowledge building takes place. What knowledge students need, how specialized and to what depth needs further investigation. One benefit of this task is that it allows students to use knowledge, to see how it operates in other contexts, and how it is problematized free from the possibly distracting procedures of laboratory practice.

A meta-analysis of group learning in science (Springer, Stanne, & Donovan, 1999) demonstrates that small group learning benefited undergraduate students in STEM subjects, promoting more sustained achievement, improving attitudes and academic persistence. Bennett, Hogarth, Lubben, Campbell, & Robinson, 2009) systematic review of small group discussions in school science lessons spanning the 11-18 age range advises the explicit development of discussion skills both in teacher and student education. While we do not differ from this conclusion, we suggest that the context of this task is an important way of identifying what knowledge and skills are exemplified, and therefore need support, when engaging in a research-based task. Our experience also shows that mixed sex groups operated effectively with both young men and women generating ideas and problematising ideas within the groups. It should be noted that not all Chinn and Malhotra's (2002) criteria were addressed. The scope of the problem did not allow for that. It is worthwhile considering what other tasks and their framing could promote discussions with a deeper research base, including how they might affect or be affected by the structure of the groups.

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THE CONDITIONS, CONTEXT AND CHARACTER OF CHILDREN'S QUESTIONS IN AN OUTREACH PROGRAM

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We present an analysis of the questions asked by students of Grades 6-12 during the course of a two-year school outreach program conducted by students from Tata Institute of Fundamental Research (TIFR) Hyderabad and University of Hyderabad. We place this work within the discourse on rote learning and a perceived lack of curiosity among Indian students in traditional school settings. Given the right conditions, students at all levels did express their curiosity through questions. Biology (especially human physiology) and physics (especially astronomy and light) were prominent fields of students' interest. Questions were often derived from everyday phenomena and not easily relatable to the curriculum. Students had questions on religion, society, humankind, and on life and career matters. Explanatory-type questions predominated followed by complex factual and open-ended questions. We identified some context dependencies of these questions. We found curiosity alive and well among students: now it's up to our ability to recognise, characterise, relate and direct that curiosity towards our mutual learning.

INTRODUCTION

Curiosity and questioning among children

Curiosity and questioning are natural to children. Infants express curiosity through looking, expressions, vocalisations, gestures and explorations (Engel, 2014). On learning to talk, children gain a powerful new tool to acquire information about the world. During toddlerhood they persistently and tenaciously seek information through questions and gather informative answers, a tendency that may be significantly shaped by family, society and culture (Engel, 2014). The rapid drop of questioning as children enter school is now well documented (Tizard and Hughes, 1984; Dillon, 1988). In Indian familial and school contexts, children are socialised to accept the authority of elders. Teacher-questioning and children-answering are the norm (Kumar, 1989). The pedagogic authority of the teacher, textbook and the curriculum reign supreme (Clarke, 2001; Sarangapani, 2003). Sarangapani (2003) documents how the teacher's questions are mainly evaluative and factual, and how they serve to establish and maintain the teacher's epistemic superiority and authority over knowledge. Students' questions, if any, are mainly procedural or clarificatory.

The value of questioning

In scholastic contexts, questions are known to improve children's ability to recall, remember and to raise their academic achievement. Studies have confirmed the relationship between curiosity and memory (Gruber, Gelman & Ranganath, 2014) and curiosity and academic achievement (von Stumm, Hell, & Chamorro-Premuzic, 2011). Suppression of children's curiosity is thus a wastage of learning opportunities in school. Meaning is mediated in education mainly through questions. Questions are an essential component of discursive activity and dialectical thinking; they direct learning and facilitate knowledge construction, and are thus a valuable resource for learning (Chin and Osborne, 2008). Inquiry-related curiosity is recognised to play a significant role in driving science learning in both formal and informal learning settings. The inquiry approach, though it draws from research on students' conceptions, may have neglected the students' own voice (Jenkins, 2006), resulting in an inattention to what students are interested in learning, or what they have difficulty in understanding. This gap might be addressed by studying self-generated questions, especially in informal contexts, e.g. as done by Baram-Tsabari and Yarden (2005) and Baram-Tsabari, et al. (2006).

Facilitating students' questioning

Facilitative conditions for questioning include meaningful scaffolds, prompts, curiosity-inducing stimuli and other supporting mechanisms (Chin and Osborne, 2008). Learning through research papers might provide a stimulus for questioning and higher thinking levels (Brill and Yarden, 2003), as also well-designed inquiry-based laboratory tasks (Hofstein et al., 2004). Singh et al. (2018) found spontaneous questioning and discussions among children in a less structured setting; by analysing children's talk and interactions with each other and with a tree (a material context), they documented authentic questions, both explicit and implicit.

School outreach program of TIFR Hyderabad

In early 2017 the TIFR Centre for Interdisciplinary Sciences, Hyderabad undertook an outreach program for three residential schools run by the Telangana Social Welfare Residential Educational Institutions Society (TSWREIS), two Girls' and one Boys' school. The program was conducted during weekends by mainly graduate or integrated master's student volunteers from TIFR Hyderabad (TIFR-H) and University of Hyderabad (UoH). It included classroom and lab sessions on curricular topics with students between Grades 6-12. Over two years 83 volunteers participated in 134 visits: a core group of five volunteers in more than 20 visits, while most attended 9 or fewer visits. Volunteers recorded a brief account of their session in a shared log file. Early on the volunteers remarked on the extreme prevalence of rote learning in the schools. Though students were lively in their interactions, curious about where the volunteers came from, what they were doing in their school, etc., they rarely asked any questions about the science content. The schools' administrators were receptive, and even suggested a 'Project Socrates' to encourage students' questions.

Then, towards the end of the first year, two of the volunteers decided to ask two classes of Grade 12 students to give their questions in writing, anonymously if they so wished. To their surprise, these students came forth with a flood of questions on a range of topics, from biology and astrophysics to philosophy and career aspects. In another school, in a session on human physiology, an experienced teacher-volunteer was able to elicit oral questions from students. Later several volunteers recorded questions, through discussion and activity sessions and events like 'Meet A Scientist'. This paper is based on an analysis of the questions data and metadata recorded in the logs from all of these contexts.

METHODOLOGY

Research questions and data

(a) What conditions and contexts can lead to students expressing their curiosity? (b) How do we characterise students' questions in a way helpful to teachers and curriculum developers?

The data is drawn from two years of school outreach from February 2017 to December 2018, during which a total of 134 school visits were conducted by 83 volunteers in three schools that followed State Board curriculum. These included 330 sessions for Grades 6-12. In 63 of these sessions 698 questions were recorded, and 49 questions were recorded in two 'Meet a Scientist' events, making a total of 747 questions analysed here. Of these 477 (64%) questions were submitted by students in written form whereas 270 (36%) were in oral form and recorded in the logs by volunteers. The information in the log records allowed us to characterise the type of sessions ('Discussion-based', 'Activity-based' and 'Meet a Scientist') and to determine whether the question was related or unrelated to the ongoing session. Observations and impressions recorded by the outreach volunteers helped in further understanding the context of the questions.

Coding and analysis

Baram-Tsabari and Yarden (2005) analysed children's questions submitted to a TV program series for 'Field of Interest' (FoI), 'Type of requested Information'(ToI), 'Motivation' and 'Source'. Of these only the first two types of analysis, 'Field of Interest' and 'Type of Information requested', applied to our data since all the questions were asked under specific and known circumstances.

The questions were first coded for FoI though a qualitative bottom-up approach; these descriptors were used as one means to validate a novel top-down coding approach. A long-term objective of our R&D program is to build a searchable database of children's questions. Seeking a standardised system of coding for subject areas we considered various library classification systems, of which the most widely implemented is the Dewey Decimal Classification (DDC) system (23rd online edition; OCLC, 2003). For appropriateness and feasibility of using a book classification system to code children's questions we consulted two librarians in two research institutes. These consultations also helped establish face validity to the FoI coding.

Baram-Tsabari and Yarden (2005) proposed a typology for ToI with six categories: Factual, Explanatory, Methodological, Evidential, Open-ended and Application type of questions. We further characterised these categories using subcategories that brought out better the nature of these questions. The coding scheme is elaborated in Table 1 in the 'Results' section.

Face validity of coding

The FoI and ToI coding schemes were fine-tuned after trials by four researchers on four separate datasets of 40 questions each collected from a different set of students. Then the dataset of 747 questions was coded in a shared spreadsheet (100-200 questions by each coder) after which the numerical FoI and ToI codes were sorted to visualize the questions grouped under each category. The DDC-based FoI codes were each reviewed by two authors followed by another round of face validity testing by a trained librarian for 65% of the data.

The qualitative codes were then used to test the internal consistency of coding. After another two rounds of sorting and agreement among all researchers, the codes for FoI and ToI were finalized.

RESULTS

The numbers of questions varied widely among sessions by different volunteers. Only 24 of the 83 volunteers contributed questions to the database. Out of 698 questions collected in 63 sessions, 468 were contributed by just five volunteers. The majority(64% of the questions) were submitted in written form. The number of questions asked by girls and boys were 587 and 160 respectively, as a result of several factors. There were 228 sessions in the two Girls' schools and 102 sessions in the Boys' school; volunteer and school-related variables may also have contributed to the difference in number of questions, hence no gender analysis is attempted. While interpreting the data however we must remember that 78.6% of the questions are contributed by girls.

Patterns of questioning

Questions posed by the students were coded as either 'related' (R) or 'unrelated' (U) to the topic of the session. In some general or motivational sessions, or when volunteers had simply asked students to write down their questions, the questions were labelled 'spontaneous' (S). The 'related' (R) questions were predominantly (70%) asked orally while the 'spontaneous and unrelated' (S+U) questions were submitted mainly (83%) in written form ($\div^2 = 208.8$; $p = .0000$). The S+U questions are crucial to our analysis as they elucidate the fields of children's interests, in which they have questions irrespective of the topic of discussion. Among 747 questions raised, 481 (64%) questions were S+U type. Interestingly, the S+U questions mainly arose in the classroom sessions (479 out of 657). In the Activity and 'Meet a Scientist' session's 88 out of 90 questions were related to the session, indicating the success of these sessions in focusing the students' attention and directing their curiosity.

Field of interest (FoI)

After some rounds of qualitative or 'bottom up' coding to get a feel for the data, the questions were coded for 'Field of Interest' using the DDC 23rd Edition, 3rd Summary (OCLC, 2003). Out of the 1000 given divisions the 747 questions fell into 115 divisions. The students' questions, especially of the 'spontaneous and unrelated' kind, arose from their experiences and reflections rather than from academic disciplines. We aimed to place these everyday questions into categories that identified the areas of study that could be brought to bear in addressing them. For example, "Why is the sky blue?" and "Why can't we see gases?" were coded under 'Light and related radiation'; "How were humans born?" and "Why are the faces of human beings so different?" were coded under "Genetics and Evolution". The detailed DDC categorisation offered systematisation of a dataset of very diverse questions, with the flexibility of combining codes as needed. It gave a standardised system of coding that could be extended to large datasets and used by experts while responding.

Questions that could not be answered through natural science or technology naturally fell under humanities and social sciences. General questions about life and death were placed in 'Philosophy and humankind' and on the existence of God were in 'Religion', both under the broader category of 'Humanities'. Questions relating to memory, emotions and dreams were placed in ‘Psychology’ and questions about money in ‘Economics’, both as part of ‘Social Science’. The humanities and social science categories were merged for the purpose of analysis. Table 1 shows the number of questions in three broad categories of ‘Field of Interest’, for 481 ‘spontaneous’ (S) and ‘unrelated’ (U) questions, which reflect the students’ own fields of interest, independent of the topic of the class. Frequently occurring subcategories and examples of the spontaneous and unrelated questions are shown. Though the majority of S+U questions (70.2%) were in the ‘Natural Science’ category, a significant number were related to religion and God, philosophy, psychology and humankind (25.9%).

FoI Question count (Column %)	**S+U count (Column %)**	**Salient sub-fields in S+U questions (%)**	**Example questions**
Social Sciences & Humanities 148 (19.7%)	125 (25.9%)	Religion & God (5.4%) Philosophy & Humankind (4.8%) Psychology (4.8%)	‘Is it true that God does wonders in people’s lives?’ ‘Why are mindsets of people different from each other?’ ‘Why can't we bear prolonged silence?’
Natural Sciences 574 (76.8%)	338 (70.2%)	Biology (37%) Physics (27%) Geology & Palaeontology (1.9%)	‘Why do members of a family not share the same blood group?’ ‘Why are all planets round?’ ‘Where do we find diesel and petrol?’
Technology 25 (3.3%)	18 (3.7%)	Applied Physics & Engineering (1%) Applied Sciences (0.8%) Biochemical engineering (0.8%)	‘Why does a fan have only three blades, why not more than three?’ ‘Why do clocks rotate clockwise and not anticlockwise?’ ‘Why is most paper white in colour?’

Table 1: ‘Field of Interest’ as seen in all questions and in ‘Spontaneous and Unrelated (S+U)’ questions

Within natural science the predominant sub-category was ‘Biology’ (37%) within which ‘Human physiology, health and diseases’ dominated at 20%, followed by ‘Botany’, ‘Zoology’, ‘Microbiology’ and ‘General Biology’ (taken together) at 17%. Within ‘Physics’ (27%), ‘Astronomy and Astrophysics’ questions were 14%, most of which focused on the Earth and solar system; only one question mentioned a black hole, “Is there anything to control a black hole?”. Questions related to ‘Light and colour’ were significant at 7.7%.

Type of requested Information (ToI)

Table 2 shows the categories of ToI, example questions and the numbers in each category. ‘Explanatory’ type of questions predominated (54.6%). The ‘Factual’ questions (overall 27.0%) were mainly complex. The next largest category (12.8%) was of open-ended questions addressing apparent contradictions or seeking opinions, predictions and futuristic possibilities on a range of topics from supernatural and spiritual aspects to open-ended advice on personal issues. Interestingly very few questions asked for evidence or applications.

Context-based distribution of ToI

The sessions with questions and the number of questions collected in each (sessions: questions) included 'Meet a Scientist' (2:49), classroom sessions (63:657) and activity sessions (3:41). Interestingly during 'Meet a Scientist' most of the questions (73%) were of factual type; during classroom sessions the explanatory questions dominated (60%) while during activity sessions procedural and methodological questions were the most frequent (54%) (χ = 285.49; $p < 0.00001$). The classroom sessions also had a significant proportion of open-ended questions (20%).

Category (question count, percentage)	**Subcategory (percentage) and example questions**
Factual (201, 27%) *Questions seeking factual information (what/ who/ when/ where/ which); simple, complex and specific academic guidance*	**Simple (7.9%)**: 'What is meant by nitrification?'; 'Name the carboxylic acid used as a preservative?'; 'Which is the coldest place (on Earth)?' **Complex (16.5%)**: 'What are the advantages and disadvantages of solar energy?'; 'Can we see all cells within a fruit?'; 'Can a person be born without reproduction?' **Seeking guidance (2.5%)**: 'How can I become a poet?'; 'Why should we study reflection?'; 'How to prepare for 10th public exam?'
Explanatory (408, 54.6%) *Questions seeking explanation of a phenomenon, process or event. (How and Why questions). The subcategories include seeking explanation for the origins, causation, function, etc.*	**Origins (3.9%)**: 'How is a star formed?'; 'How did life begin on Earth?'; 'How did the Earth come into existence?' **Causation (35.3%)**: 'Why do we get irregular periods, pain at the time of menses and cysts in uterus?'; 'Why does a chameleon change colour?'; 'Why do men get bald more in comparison to women?' **Function / Mechanism (8.9%)**: 'Why does our brain have nerves, what is the use of it?'; 'How is soil formed?'; 'How can we replace plastic with other things on the earth?' **Connections and contradictions (4.7%)**: 'Why do we intake only oxygen and not nitrogen?'; 'Why plants are called living things when they do not move?'; 'Why is technology growing (so rapidly) on Earth? What are its benefits and disadvantages?' **Practices and Conventions (1.9%)**: 'Why don't we start counting from zero?'; 'Why is the school bus yellow in colour?'; 'Why do hospitals have a + symbol?'
Procedural / Methodological (37, 5%) *Questions seeking description for a specific procedure or methodology, including scientific experiments, medical procedures, theoretical subjects, everyday life issues etc.*	**Related to subject of study or an experimental demonstration in class (3.6%)**: 'Is there any process to harden the foam to form a sponge?', 'Why does dividing by zero give a 'not defined' value? Shouldn't it be zero?'; 'Why do we use only bacteria, for demonstrating microbial growth experiments?' **Related to practice of some field (within science, technology and economics) (0.5%)**: 'How do doctors replace the heart?'; 'How do astronauts go into space?'; 'How do scientists find the elements?' **Related to life issues/everyday world/environment (0.8%)**: 'What should we do to decrease pollution?'; 'How do people with (physical) disabilities swim?'; 'Why does corruption go on in our country? How can we stop it?'

Category (question count, percentage)	**Subcategory (percentage) and example questions**
Evidential (3, 0.4%) *Seeking evidence*	'How can we believe cells grow?'; 'Who is God? How? Why? I don't want to see but I want proof or a particular reason'; 'How do we know that 'atom' is the smallest constituent of matter?'
Open-ended (96, 12.8%) *Questions seeking opinions, suggestions, predictions as well as contradictions within existing facts, futuristic possibilities, supernatural and spiritual aspects, and open-ended advice on matters*	**Counterfactual (1.1%)**: 'Why do we want money?'; 'How can a poor one become a rich one?'; 'Why don't people live in other planets?' **Predictive (0.4%)**: 'What will happen if planets stop revolving?'; 'What would have happened if there were no bacteria on the planet?'; 'How long do cancer survivors live?' **Futuristic (1.9%)**: 'If mars get polluted where do we go in the future?'; 'What will Chemistry do in the next 20 years?'; 'Can we produce electricity from plastics?' **Seeking general advice (3.6%)**: 'How can we learn all the concepts of optional subjects?'; 'How to remember everything?'; 'Why do we remember all the things other than studies?' **Existential (1.7%)**: 'Why do we have to be born and die after spending some years on the Earth?'; 'Are humans of any use for the Universe?'; 'Why are we born and why do we die?' **Spiritual / supernatural (4.1%)**: 'Is God there or not?'; 'Why do people believe in superstition?'; 'Does the devil exist?'
Application (2, 0.26%)	'We would love to have our school powered by green energy. Could it provide electricity for our school? Is it long lasting?'; 'How will this experiment help in our daily life?'

Table 2

Inter-relationship between ToI and FoI

Does the type of information requested (ToI) vary according to the subject area in which the question is asked? Figure 1 indicates that 72% of questions in 'Biology' and 60% of questions in Physics were Explanatory in nature. On the other hand, questions in 'Humanities & Social Sciences' were majorly of open-ended type (48%). A minimal proportion of Open-Ended questions appeared in other subjects, except 'Chemistry'. The Type of Information requested significantly varied by subject areas ($\chi^2 = 302.14$; $p < 0.00001$).

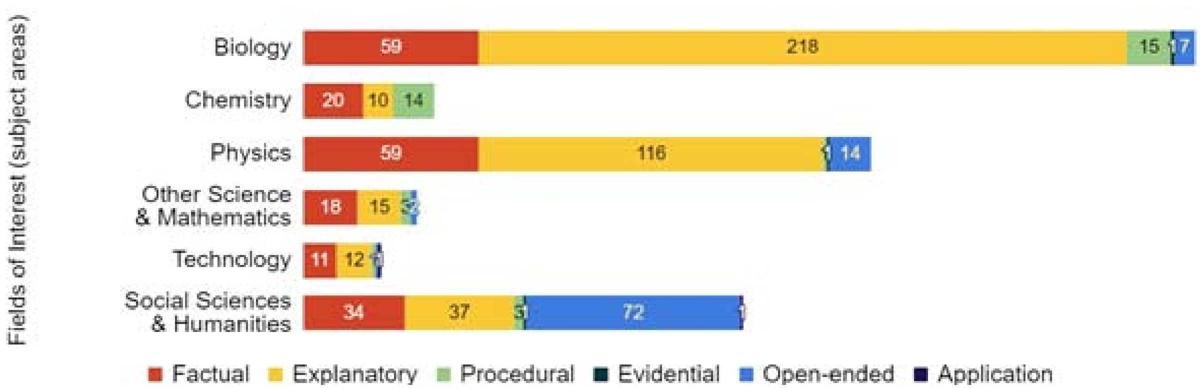

Figure 1

CONCLUSIONS AND FUTURE DIRECTIONS

A significant result from this study is actually implicit in our data. It is about the ease with which many of the volunteer-teachers could break the stereotypical classroom pattern of 'teacher questions - student answers'. Volunteers noted the non-hierarchical nature of the dialogue and the realistic possibility of response which encouraged questioning. It helped that they had an explicit mandate to solicit and record students' questions. The volunteers were highly capable graduate and masters science students and, in one case, a reflective, experienced teacher. All were themselves curious, had access to information sources and, most importantly, were part of a supportive community of scientists and science learners. Other favourable conditions included written and anonymous questions, meeting scientists (for factual queries) and science activities (for methodological queries).

The task of addressing students' questions is barely begun. In the next phase of the outreach program the database of students' questions in specific areas is made available to the volunteers as an aid to prepare their sessions on the basis of students' spontaneous interests. On a wider scale students' questions have implications for curricula in science and social studies, after the database gets inputs from more diverse groups of students. Learnings of the outreach program has led to a collaborative R&D project with Eklavya (Madhya Pradesh), aiming to create the 'Sawaliram' website with a digital repository of students' questions from various contexts and language backgrounds from across India. This repository will be part of a multilingual interactive open source platform to collect, answer and analyse children's questions. The web platform would host resources for parents, educators, curriculum developers and researchers on the topic of curiosity and questioning among students.

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BRIDGING A CULTURAL GAP BY TRANSFORMATIVE STEM LEARNING IN RURAL INDIA

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The importance of STEM education for the future workforce has been recognised globally. Increasing teachers' capability to teach STEM subjects is consequently essential. While the race to build STEM education in developed countries has been fast, rural areas in developing countries which are already suffering from the lack of daily resources are left further behind. A team of STEM educators from Curtin University in collaboration with a Regional Institute of Education (RIE) Bhopal conducted a professional learning program for rural teachers in India. This paper discusses the evaluation of this program. It was found that the gap between the participating teachers' understanding and skills was complex and mostly cultural. In order for this program to achieve its intended aims, this gap must first be bridged.

PURPOSE OF THE STUDY

This paper reports on a Science, Technology, Engineering and Mathematics (STEM) professional learning program conducted by a team of two researchers from Curtin University at The Regional Institute of Education (RIE), Bhopal. The aim of this program was to build the capabilities of teachers to teach STEM activities and prepare their students for the 21st century learning. Face-to-face workshops were delivered for three days, supported by online contents using Moodle as the learning management system.

The participants of this program were 44 in-service teachers from the Ichhawar Block, a village located near Bhopal in Sehore district in the state of Madhya Pradesh, India. The literacy levels of Ichhawar are 77%, which is slightly higher than the state average of 70% (Census of India, 2011). The number of men who could read and write (86%) was considerably higher than women at 67% (Census 2011). The employment rate in Ichhawar was around 35%, with only one third of females in paid employment. Agriculture is the main occupation of the population.

This paper starts with a vignette, based on lived experience of researchers on the first day of the workshop. These short vignettes are considered very important for setting the scene for readers to know the working conditions to which researchers had to adopt and has been written in first person.

> ***Vignette 1:*** *Both of us, were enthusiastically looking forward to working with teachers in RIE. Year earlier we had already worked with pre-service teachers in this campus, who were brilliant and had greatly appreciated our way of engagement and efforts. Based on our success in making*

an impact on pre-service teachers and experience of identifying gaps, we were successful in securing an Australian Government grant to create online teaching modules for science teachers. Moodle platform was thought to be best suited for this training programme, as this would allow participants to work on multiple platforms. We were aware of most adults having smart phones in India, on which the Moodle app can be downloaded.

We were escorted to the conference room, where participants were already seated. After the introductory welcome from the Principal, we were also asked to say a few words which we have sort of learnt following local protocol. This trailed participant teachers introducing themselves – their names, area and level of teaching and finally expectations from the workshop. I was expecting participant teachers from the schools of Bhopal. To my dismay most (39) teachers were from a so called tribal village, and rest of the five teachers from a constituent school called multi-purpose demonstration school on the campus of RIE, Bhopal. We realised we are in for a challenge but were determined to navigate and draw on the principles of transformative learning (Mezirow & Taylor, 2011). However how effective would it be, we questioned ourselves…without giving a whiff of what was going through our mind out?

PERSPECTIVES

Transformative Learning and Culture

The term *transformative learning* was first introduced by Mezirow in 1978 to highlight adult learning as a meaning-making personal process that leads to personal transformation and growth (Mezirow & Taylor, 2011). In its development, transformative learning evolves to include social transformation as part of personal transformation. Within transformative learning there are three core elements that are considered to be influential to the personal and social transformation, which are individual experience, critical reflection and dialogue, and holistic orientation. Individual experience forms the beliefs and understanding which learners bring into the classroom. Mezirow and Taylor further explicated that "value-laden course content and intense experiential activities offer experiences that can be a catalyst for critical reflection and can provide an opportunity to promote transformative learning" (p. 6). Critical reflection and dialogue provide the process in which existing beliefs and understanding are confronted, compared and contrasted. Holistic orientation is the link between cognitive and affective aspects of learning, or as Kolb and Kolb (2009) stated "the integrated functioning of the total person – thinking, feeling, perceiving and behaving. It encompasses other specialized models of adaptation from the scientific method to problems solving, decision making and creativity" (p. 43).

Teacher professional learning as adult learning activities seeks to adopt transformative learning if it is to be effective. Professional learning programs are designed to entrench the three core elements by recognising teachers' previous learning, cultivating critical reflection and dialogue, and addressing the cognitive and affective learning processes (Berry & Forgasz, 2016; Meijer, Kuijpers, Boei, Vrieling, & Geijsel, 2017; Sprow Forte & Blouin, 2016).

Within the theory of transformative learning, culture is deeply embedded. Culture strongly influences all three core elements of transformative learning, hence it could help or hindrance learning. Hofstede, Hofstede, and Minkov (2010) explicated the layers of culture in the national level, religion/ethnic/region/linguistic affiliation level, gender level, generation level, social class level and organisational level. Cultural identity formed from these levels creates unique individuals who in fact belong to different groups. As long as there is no friction between these groups, an individual's cultural identity can remain indistinct. Cultural identity forms the way we learn; it directs the way we think, feel, perceive and behave.

The national level of culture creates the national cultural identity. While the broadness of this level means there are generalisations made in identifying the cultural aspects. (Hofstede, Hofstede, and Minkov, 2010) categorised six dimensions of national cultures: power distance, individualism, masculinity, uncertainty avoidance, long-term orientation and indulgence. Power distance indicates how hierarchical the society is; individualism is defined as the opposite of collectivism; masculinity represents gender-related attachment on professions, earnings and others; uncertainty avoidance indicates the way the society deals with uncertainties of the future; long-term orientation suggests that the society tends to plan for the future and places less value on preserving traditions; indulgence refers to the value the society places on happiness and enjoyment. Figure 1 illustrates how Australia and India were measured on these six dimensions. https://www.hofstede-insights.com/product/compare-countries/

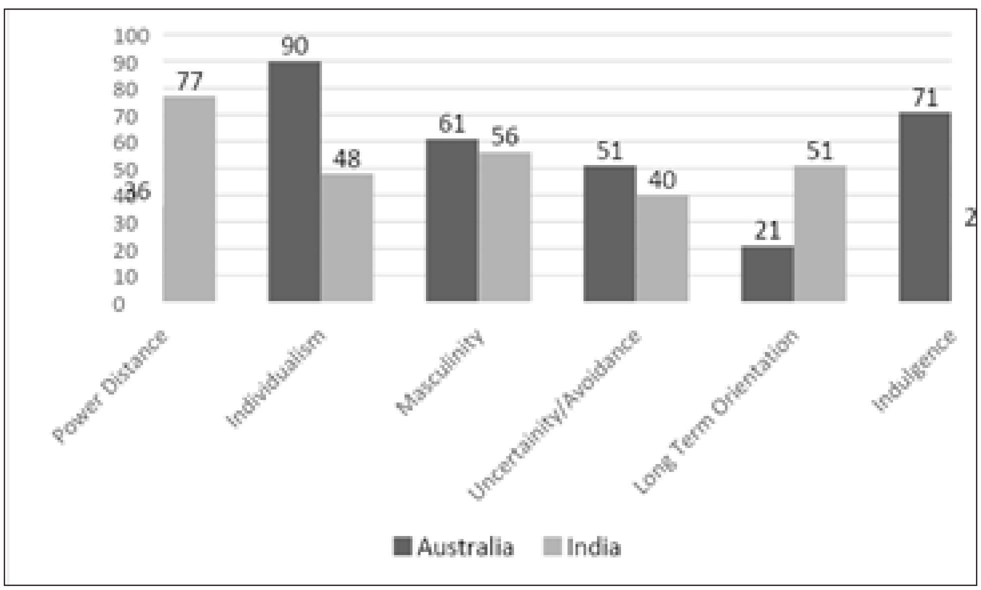

Figure 1. Australia-India country comparison (Hofstede, 2019)

Vignette 2: *We enter a room roughly 6meters by 6meters dimensions, furnished with chairs and desks and 40 desktop computers on the desks. There is a screen and a desktop for the instructor (us) in the front as well. Each piece of furniture is closely placed to accommodate every piece of furniture in this reasonably small room leaving very little space for moving around. We have* *three of RIE's technical staff helping with getting participants started. Participants were asked to log on to the Moodle site for which they should have received an invitation e-mail from us. To our dismay most of them didn't know anything about it, instead expected us to give them their e-mail passwords. This was a second jolt, were we making teachers question their self-efficacy which has potential to impact their professional beliefs?*

TEACHERS' PROFESSIONAL BELIEFS

Teachers' professional beliefs have been found to closely influence their instructional practice (Buehl & Beck, 2015; Schraw & Olafson, 2015; Tondeur, Van Braak, Ertmer, & Ottenbreit-Leftwich, 2017). Furthermore, teachers' self-efficacy, or their perception on their ability to perform professionally, has also been correlated with their competency as well as their willingness to integrate new components to their teaching (Kavanoz, Yüksel, & Özcan, 2015; Keser, Karaoglan Yilmaz, & Yilmaz, 2015).

Digital Divide and Culture

It has been around 25 years from when the term *digital divide* became increasingly popular to highlight the gap in terms of computer ownership, internet access, or information access (https://wiki.p2pfoundation.net/Digital_Divide, http://www.newworldencyclopedia.org/entry/Digital_divide;). When this term was first used, there were growing concerns that the gap would create even bigger gaps in economic growth, social structure, productivity, political participation and all the other aspects of human life (Hacker, Mason, & Morgan, 2009; Warschauer, 2004). Digital divide was predicted to create inequalities.

Now, 25 years from then, the digital divide and the inequalities it created have grown much more complex and were evident in the workshop we were about to deliver. We as researchers are entering a cultural space not fully unknown to us but still had taken certain factors like all teachers would be using e-mails for granted, and our host although informed that the workshop involves using an online platform should have been careful in choosing the participants. So we had to slow down the pace of instruction and also abolish some of the planned content in the training modules.

THE FRAMEWORK

This study adopted an evaluation framework that considers the participating teachers' readiness and beliefs as influenced by the local and national cultures as important aspects that affect the impact of the program.

Teacher Beliefs are considered as the product of personal experience and learning. These professional beliefs are constructed from their technological, content and pedagogical knowledge as well as their self-efficacy. Their readiness to explore and learn from the program are informed by their professional beliefs and their technology affordances. The professional learning program was expected to upscale their pedagogical knowledge and instructional practice in the classroom, their understanding of STEM subjects and activities and their experience in technology integration in teaching and learning.

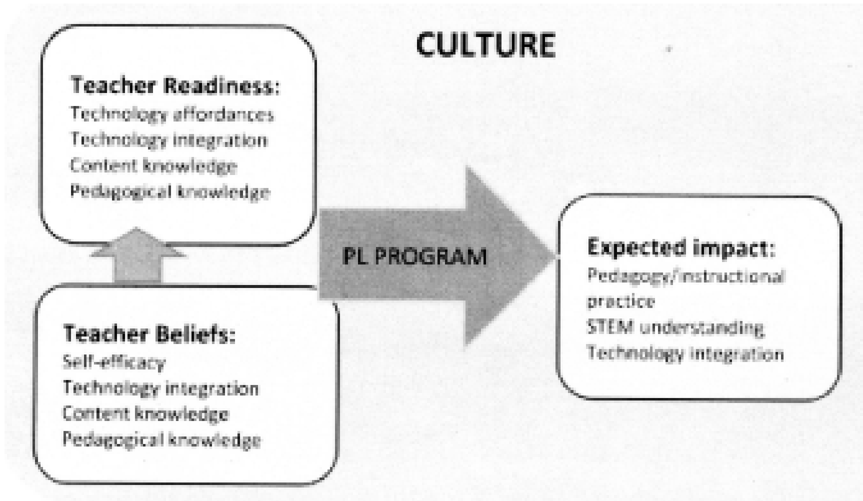

Figure 2: The program's framework

METHODOLOGY

This paper examines the effectiveness of the professional learning program, by probing into the taken for granted practices between the participants and workshop deliverers. The case study research inquiry method is adopted to analyse data obtained from the observation and pre- and post-questionnaire to build an understanding on teachers' transformational learning in rural India. The factors that were considered important to address are:

- Teachers' affordances of technology
- Teachers' self-efficacy in STEM teaching
- Impact of workshop

44 teachers from Ichhawar village, Madhya Pradesh participated in the professional learning program. Among these 44 teachers, there were 30 male teachers and 14 female teachers. Most of them were experienced upper primary science teachers with only one beginning teacher. The teachers' English skills were low to intermediate, thus required instructions and in Hindi while completing the questionnaire.

Pre workshop and post workshop survey was completed by all participating teachers on the current practices on use of technology in their teaching and their perceived usefulness of the workshop.

RESULTS

> ***Vignette 2:*** *First day of workshop was hard work, largely stressful and we had to pitch down the contents planned for delivery. On second day when we enter the workshop venue 41 of 44 participants are busy surfing something on their phones – all of them had downloaded Moodle app and were surfing the workshop website, accessing the resources provided and each one of them had questions for us.*

A small effort on our part was the start of a huge learning curve for these participants. Their learning was not going to stop at this website, instead they were introduced to art of Curating which would help in professional learning.

Teachers' affordances of technology

Responses on teachers' affordances of technology indicated that most of the participating teachers have not had much access to technology aside from mobile phone. Internet access is also mostly limited to their mobile data. Among the 44 teachers, more than 25 did not own a computer, laptop or tablet but only three did not own a mobile phone. Their use of technology was very limited, Facebook and WhatsApp was used by all in possession of a smart phone. None of them had access to computer, thus were unaware of any of the computer programs which includes basic computer navigation skills. Most teachers felt limited self-efficacy in STEM teaching skills. Teachers recognised importance of STEM skills in curriculum.

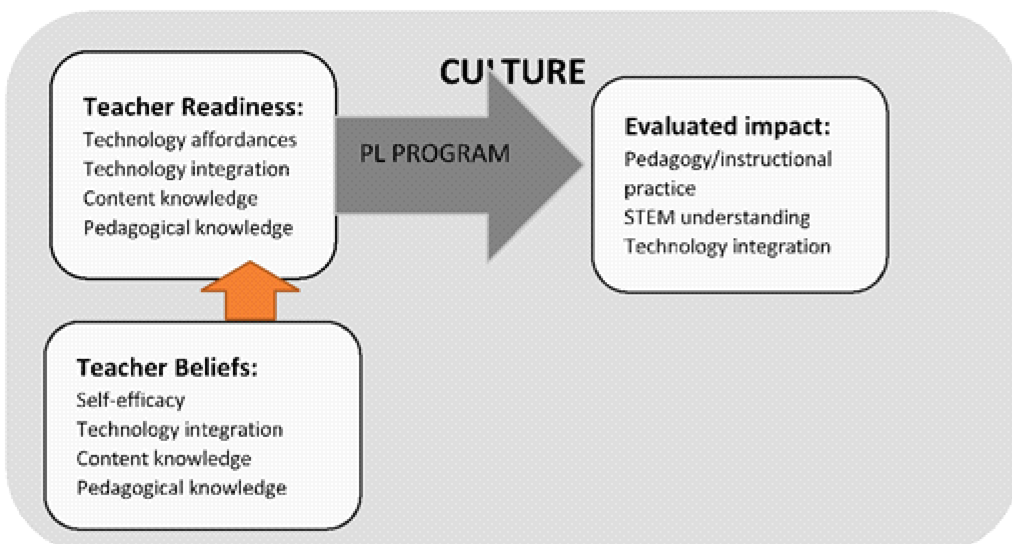

Figure 3: Bridging the gaps

All participants agreed with positive impact of following four factors on teaching outcome expectancy: (i) teacher excreting extra effort; (ii) taking responsibility for students' learning; (iii) students' learning being directly related to their teacher's effectiveness in teaching and (iv) minimal student learning generally being attributed to teachers.

Teacher Leadership attitudes identified as the teacher taking responsibility for learning, communicating vision, using a variety of assessment data throughout the year to evaluate progress, using a variety of data to organize, planning and setting goals, establishing a safe and orderly environment and empowering students. Most participants were not aware about the STEM careers and found the workshop impactful in increasing their confidence to teach STEM subjects. After the workshop, teachers felt more knowledgeable about STEM international, project based and problem based.

SIGNIFICANCE OF THE STUDY

Teachers' experience from the workshop was generally, "good experience", "enhancing teaching" and the ability to use email and computer. Findings from data analysis indicated that there were gaps between the professional learning program and the participating teachers' cultural identity, beliefs, instructional practice and technology affordances. Figure 3 illustrates these gaps in contrast with the program framework, which need to be taken into consideration by a large country like India.

Through this professional learning programme the participants were introduced and inducted into use of technology (mostly mobile phones) for if only the digital divide was abridged impact would be many-fold.

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IMPROVING THE HIGHER-ORDER THINKING SKILLS OF MIDDLE-SCHOOL STUDENTS USING ACTIVE LEARNING PEDAGOGY

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The focus of our study is to improve the higher-order thinking skills in middle-school students by exposing them to active learning methodology and an increasing number of higher-order thinking questions. The preliminary results of this longitudinal study show an improvement in the quality of discussions and questions posed by students in sessions, suggesting an enhancement of higher-order thinking skills, as a result of exposure to active learning methodology.

INTRODUCTION

While most teachers would agree that the purpose of schooling is not just to enable students to recall facts and statements, but also to be able to apply that knowledge to real-life scenarios, schools rarely ensure that students are equipped with the skills to do so. These skills, which come under the bracket of higher-order thinking skills (HOTS), are essential for a school curriculum in order to create individuals who, in school as well as outside, think critically, analyse situations objectively and make rational judgements. HOTS is a concept which is prescribed by various learning taxonomies like Bloom's and SOLO (Chan, C. C., Tsui, M. S., Chan, M. Y., & Hong, J. H., 2002), and is widely regarded as referring to the cognitive abilities that enable one to apply, analyse, evaluate and create (Bloom, 1956; Krathwohl & Anderson, 2009).

Despite its significance, many schools find the concept of higher-order thinking ambiguous, and specifically, find it challenging to help students develop it. Miri, David and Uri (2007) suggest that "*the design and implementation of teaching strategies that enhance higher-order thinking among students are not a simple endeavor; they challenge even the most expert teachers.*" Both healthy classroom discussions and the freedom to explore are necessary in order to not only gain an in-depth understanding of science, but also to develop a critical bent of mind in individuals.

From our observations, a large number of formal schools still employ the expository method to teach science in classrooms. Firstly, this method results in a one-way interaction between teacher and student, with little or no scope for students to voice their opinions or doubts. Secondly, it does not allow for students to explore scientific concepts or experiment with ideas, and mainly reinforces students' lower-order thinking skills.

Active learning, however, involves the active participation of students in the learning process, not only passively listening to the teacher (Bonwell & Eison, 1991). As Meyers and Jones (1993) indicate,

> "active learning provides opportunities for students to talk and listen, read, write, and reflect as they approach course content through problem-solving exercises, informal small groups, simulations, case studies, role playing, and other activities—all of which require students to apply what they are learning."

The purpose of our intervention was to observe if active learning pedagogy improved students' higher-order thinking skills.

The diagnostic tools used by the authors in evaluating changes in students' HOTS were based on the Revised Bloom's Taxonomy (Krathwohl & Anderson, 2009). Two main indicators were identified:

a. Quality and correctness of answers given by students to higher order thinking questions asked in their assessment (which were mapped to various levels of Revised Bloom's Taxonomy), and
b. Quality of classroom discussions and student questions.

Therefore, in light of the discussion above, the authors, through this study, aim to observe if active learning methodology causes an improvement in the higher-order thinking skills of students.

METHODS

Study sample

A total of 40 students studying in Class 6 at a school in Bengaluru, affiliated to the CBSE curriculum, were involved in the study. The students were segregated into two sections (A & B) of 20 students each by the school at random, prior to the study. Students of both sections were taught science concepts through active learning methods that included hands-on activities and experiments. These were designed by the authors in consultation with peers and colleagues from their organization. This project began on 21 May 2018, and is still underway. This study does not have a control group as it is a longitudinal study to observe changes in students' HOT skills over a period of time.

Session timings

The chosen school allocated 240 minutes for Science for each section, per week. In order to facilitate the following: (i) in-class activities, (ii) leading questions to be asked in class, (iii) self-reflection, and (iv) elaborate discussions and deliberations by students, the intervention took place in block sessions that lasted for 80 minutes each on Mondays, Wednesdays and Saturdays.

Preparations for the sessions

The topics chosen for the year included the 16 chapters developed for Class 6 by the National Council of Educational Research and Training (henceforth, NCERT), and a few additional topics chosen by the authors. Each topic was developed in the form of learning modules. The learning objectives of each chapter of NCERT were written down, and modules were developed such that the learning objectives of the NCERT chapters were achieved. The modules included active learning techniques, such as activities, experiments, demonstrations, leading questions and explanations. The authors planned the order of these topics in a logical manner. Once the modules for each topic had been finalised, along with the lesson plan, the facilitators presented demonstrations to their colleagues, who provided useful feedback to be considered for the sessions in the school. The demonstrations were conducted by simulating a classroom environment as far as possible.

Facilitation

The authors of this study were the facilitators who devised teaching-learning methods modeled on active learning pedagogy. One facilitator acted as the main facilitator who was responsible for facilitating a science topic using active learning methods. Two other facilitators acted as observers, who noted down the questions that students asked during a session. They also noted down class attendance, student participation in class discussions, student interaction with their team members and also gave critical feedback to the main facilitator after a session.

Pedagogy

At the beginning of each month, the 20 students of each section were divided into 5 groups of 4 students each, consisting of both boys and girls. Each student in a group was assigned one of these roles: Materials Manager, Record Keeper, Leader and Spokesperson, to ensure that all students handled responsibility and also participated actively during activities or group discussions. Groups were formed each month based on these roles, to ensure that all students held each role at least once.

In order to implement active learning pedagogy in our sessions, the implementation process for each module consisted of the following steps:

1. A *Pretest* was provided to each student at the beginning of a new topic, to gauge the preconceptions and misconceptions, if any, about the topic and also to test some of the prerequisites that the students needed for the module.
2. After the pretest, wherever necessary, students were prodded to recall the topics dealt with in the previous session(s). In cases where the topics required specific prerequisite knowledge, it was ensured that the students learnt the prerequisite material adequately before proceeding with the modules.
3. The introduction to the module was through one or a combination of the following: visual aids (videos, pictures), oral explanation and demonstration activities wherever necessary.
4. *Activity Sheets* were provided for each topic to the students. These activity sheets contained leading questions about their day-to-day observations, instructions for activities, space to note down their observations and conclusions from the activities and leading questions to get to a conclusion about a concept.
5. This was then usually followed by a set of activities, oral explanations, or detailed discussions, or all three, catering to the learning objectives of that topic. Students were continuously encouraged to read through the instructions and perform each activity prescribed in the activity sheet by themselves, although they could take the help of their group members. All the activities were followed by a consolidation, during which the objective of that activity was made clear to the students.
6. At the end of a topic, students were made to draw a mind-map related to the topic (refer Figure 1). Mind-mapping is known to be a powerful tool to facilitate better recall of the concepts related to a topic (Buzan & Buzan, 1993). Mind-map also helps the facilitator to get a clear picture of student's state of understanding and creativity of the topic.
7. Each topic was followed by a short quiz (called Check Yourself), designed to -
    a. help students and facilitators evaluate the level of student's understanding of the topic, and introduce and expose students to questions that assessed their higher-order thinking skills.

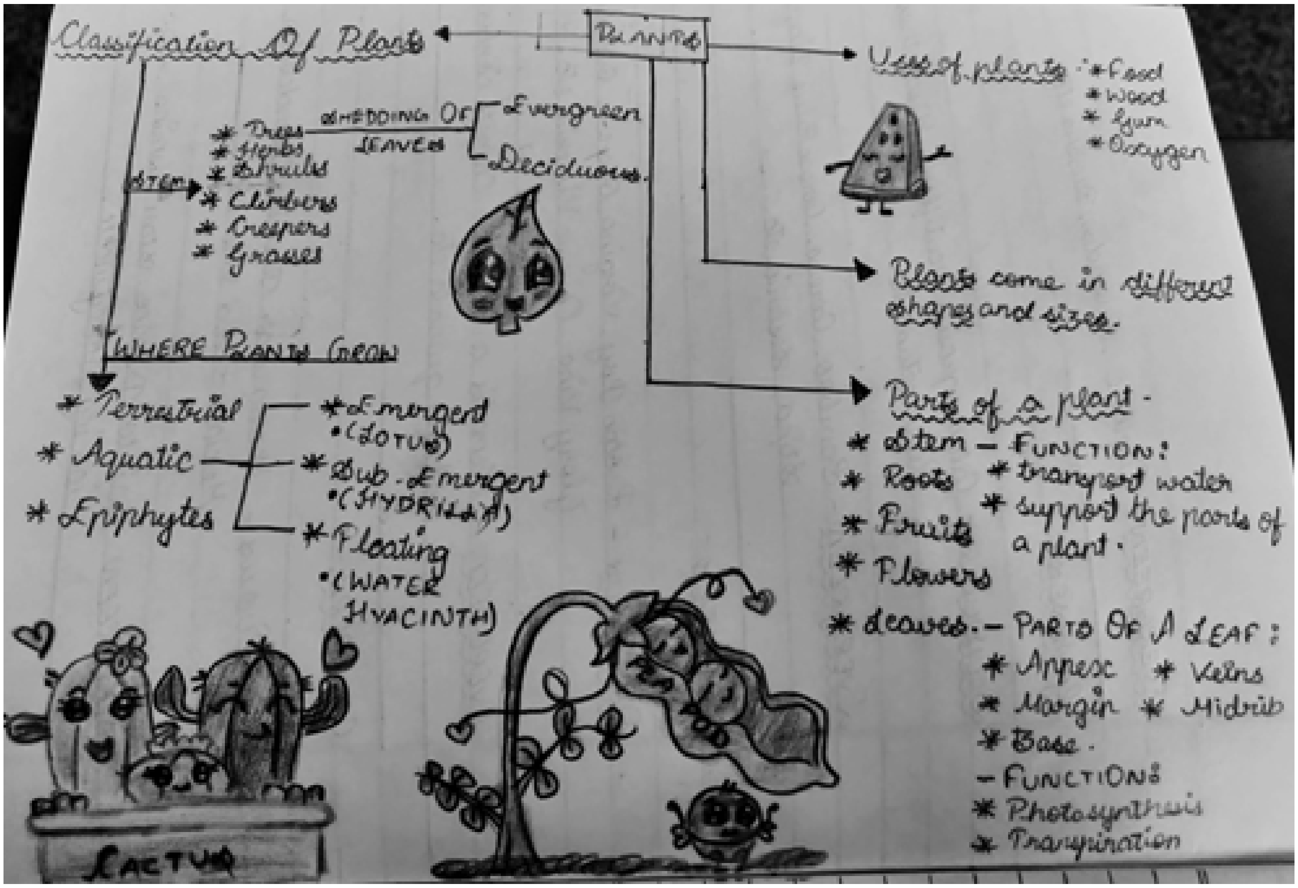

Figure 1: A Mindmap on the lesson 'Plants' done by student M

Along with these, students also underwent formative and summative assessment, took part in in-class quizzes, group discussions and debates, answered worksheets which had HOT questions, watched educational videos and documentaries, delivered presentations on chosen topics and participated in innovative revision games.

Evaluation Methods (HOTS Assessment)

Students underwent periodic assessment in the form of formative and summative assessments. Formative Assessment was given in two forms -

1. Each topic, on completion, was followed by a short quiz (check yourself), consisting of a set of five questions. This quiz was not graded.
2. Students also attended monthly Unit Tests (prescribed by the school), which were scored out of 25 marks, which, apart from accomplishing the goals of the quiz, tested what students learnt in that particular month.

Summative Assessment was given in two forms, both prescribed by the school -

1. A mid-term examination was conducted halfway into the academic year, including the topics covered in

the first half of the year.

2. A final examination was conducted at the end of the academic year, consisting of the second half's portions.

All the questions asked in the formative and summative assessments were mapped to the cognitive levels of Revised Bloom's Taxonomy. The assessment consisted of a range of questions, varying from the lowest (remember, understand) to the highest (apply, analyse, evaluate, create) levels of Revised Bloom's Taxonomy, which were either chosen from standard questionnaires or designed by the authors themselves. The assessments also consisted of different types of questions, including multiple-type questions, fill-in-the-blank questions and short-answer and long-answer questions.

Students' answers to these questions were primary indicators of the outcome of our intervention. Each successive assessment had an increasing number of HOTS questions, and was intended to (i) test students' grasp of the topic, (ii) expose them to higher-order thinking questions, and (iii) observe significant changes in their HOT skills, if any.

RESULTS

The authors feel that, since this is a longitudinal study, one year's data would be insufficient to draw any significant conclusions about the effect of active learning on students' HOT skills. However, preliminary results show that, in the first year of this study, students showed an improvement in the quality of discussions and questions asked in class.

Presented below are a few case studies highlighting the improvements in HOTS that were observed in students during the course of our intervention, in the form of student answers to HOTS questions and in-class questions posed by students during sessions.

Case Study 1: *Student answer to a HOTS question*

In the mid-term examination, student **IS** was able to produce an appreciable answer to a HOT question belonging to the cognitive level of **'analyse'**. The question is as follows -

'Cobalt chloride is a chemical which is pink in colour when wet and blue in colour when dry. Using this information,

A) Write the procedure for an experiment to observe transpiration in plants.
(Materials available: A plant, cobalt chloride paper, clips)

B) What are your expected results?

C) Give a reason for your expected result.'

IS's answer is as follows:

> *"First make a solution [of] Cobalt chloride and mix it [with] water. Take a beaker and pour the solution [in]to it. Then keep the plant and cut the stem into half and put it [in]to the water [and] leave*

it. Then after take a polythene bag. The plant that you kept in the cobalt chloride should be taken out. The leaves had to [be tied] inside tie the polythene bag. Place the plant in the sunlight [and] observe if the pink color water drops are there."

Observations: IS's answer reflected her HOTS, and provided the authors an insight into the thinking processes that went into producing the answer. IS was able to use her reasoning ability and creativity. In this case, IS has combined two experiments. Although the expected answer from students was an experiment to verify transpiration by attaching the cobalt chloride paper to the leaf, she demonstrated her remarkable ability to connect two concepts and use the outcome of the other experiment as a procedure here.

Case Study 2: ***Student answer to a HOTS question***

In the final examination, student **PK** was able to give an explanation to a HOT question belonging to the cognitive level of **'apply'**. The question is as follows -
'Sania set up an experiment. She recorded her findings in Table 1 (See Figure 2). *Which question among A, B or C was Sania testing? (Choose the most suitable question)*

A. How many paper clips can you pick up with a magnet?

B. How many trials are needed to pick up the most paper clips?

C. Does the strength of magnetism increase if more magnets are used?'

	No. of paper clips picked up		
No. of magnets	Trial 1	Trial 2	Trial 3
1	8	9	7
2	13	16	14
3	22	23	24

Figure 2

PK's answer is as follows -

Option C. Yes, the strength of magnetism increases if more magnets are used. [When] the strength of the magnetism increase[s] if more magnets are used. The power of magnetism gets stronger and can attract the most number of clips.

Observations: Although the question did not expect for an explanation for their answer, PK provided an accurate explanation. The idea that the strength of magnetism increases when there are more number of magnets has been well described. The clarity in the explanation shows PK's reasoning abilities and application skills.

Case Study 3: In-class Questions: ***questions posed by students in sessions***

30.11.2018, Friday
Main facilitator: SD
Questions:

- Student RA: Why can't microbes decompose inorganic things?; Is compost & manure same?
- Student M: What is the substance used to make plastic?; If we add plastic to manure, will there be any disturbance for composting?; If we add seeds to compost, will it grow or become compost?

- Student V: Do vegetables and fruit peels take the same time to decompose?
- Student K: Is the amount of compost generated the same as the amount of waste thrown?

Case Study 4: In-class Questions: ***questions posed by students in sessions***

29.09.2018, Monday
Main facilitator: SR

Questions:

- Student RG: 'What holds the organs in place? Why don't they fall down?'
- Student S: 'Why do they say sit straight else we'll become a hunchback?'
- Student S: 'What is backbone and spinal cord?'
- Student RA: 'Why is the bone white and not red?'
- Student RA: 'Why do we need sternum?'
- Student M: 'What happens if bone becomes red and bone marrow is white?'
- Student M: 'Why do we only have 24 vertebrae?'
- Student K: 'How is Ca deposited in the bone?'
- Student AT: 'Cartilage is like a glue'
- Student AM: 'Who invented the X-Ray?'
- Student MG: 'Who discovered Skeleton?' ;
- Student H: 'Early man used to eat meat no?'
- Student RW: 'What would happen if we didn't have backbone?' ; Everyone else: 'We couldn't stand up straight' ; RW: 'Then why do cockroaches not stand up straight'

DISCUSSION

This study looks at active learning methodology as a means to improve the HOT skills of middle-school students. We expect that subsequent years of exposure to active learning methodology would increase the quality of classroom discussions, the questions asked in class and the number of HOT questions answered correctly in assessments, indicating an overall enhancement of the students' HOT skills.

The authors have described below a few methods to enhance students:

Improving Reading Comprehension
One revelation that the authors came across while facilitating was that students' English reading comprehension and communication abilities directly affected their performances in the assessments. The authors predict that improving students' English reading comprehension abilities would significantly change the way a student in the Indian context engages with the reading material provided to them.

Practising higher-order thinking
Although students were given short quizzes at the end of every topic, it was observed that students needed to be given more practice in higher-order thinking. As Willingham (2009) suggests, tasks that are more

complex tend to seem less difficult to interpret when practiced. A gradual increase in exposure to HOT questions, with instructional scaffolding wherever necessary to help students transition from simple to complex questions, and activities that make students analyse, apply and make judgements, would trigger a significant shift in their ability to answer HOT questions, and subsequently, their HOT skills.

CONCLUSION

At the time of submission of this paper, further work on this study is ongoing. Although it is too early to draw conclusions from the data, there are some results that show that students subjected to active learning methods have shown a positive shift in their HOTS as observed during discussions, classroom interactions and answer assessment questions. In further years, we aim to continue student exposure to active learning in order to observe its effect on their HOTS.

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TEACHER BELIEFS AND THE TAMIL NADU EDUCATIONAL REFORM 2017

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Triggered by a tragic suicide of a medical aspirant and the poor performance of the students from state schools in the NEET competitive exam, Tamil Nadu revised its curriculum, syllabus and textbooks in 2017. The paper is reflection of the author on the 'teacher beliefs' on the goals and aims of reform, their role in the reform and classroom, nature of science, and the inequities and its impact on the reform process. The recount, evidently, tainted by subjectivity, still can contribute to understanding the ways in which 'teacher beliefs' influence the selection of content and organisation of the teaching learning in state run schools.

INTRODUCTION

The author was the chairperson for the textbook committee on science for classes VI to X for revising the curriculum, syllabus and textbooks for the schools affiliated to Tamil Nadu State Board of School Examination (TNSBSE) recently. The range of response the reform initiative received was instructive of multiple voices that make up the educational edifice. The revision was undertaken with much enthusiasm and expectation. Educational reform ultimately has to have an impact on the actual classroom practice. How far will the new features of the textbook find a reflection in the way classroom interaction is conducted? This crucial question is closely linked with the 'teacher beliefs' on goals and aims of school education, the meaning of 'teaching', 'science', 'nature of science' and the role of textbooks. These beliefs influenced the contours of the shaping of the revised curriculum, syllabus and textbook.

This paper is a summary of some of my reflection on 'teacher beliefs' as an insider-participant in the process of this educational reform. As the recount and reflection is based on subjective, but reflexive interactions, which often went unrecorded, this paper may lack the usual 'distance' and 'objectivity' that one would expect from a scientific study, nevertheless, as a reflexive experience, these may provide some insights into the actual dynamics of the educational reform, various actors involved in the process, and varied concerns that shape the reform.

THE CONTEXT

Tamil Nadu (TN) government had earlier abolished all entrance exams and granted admission to coveted medical and engineering courses based on the marks obtained in the higher secondary examination. Dismissing these claims, the Supreme Court bench verdict delivered on April 11, 2016, made all admissions to medical colleges subject to obtaining a rank in the National Eligibility cum Entrance Test (NEET) (see Shanbhag (2016) for an overview of issues with NEET examinations).

The tragic suicide of Anitha, 18, an aspiring medical student, who had excelled in her school exam but had done poorly in the NEET and could not get a medical seat resulted in a public outcry. Furthermore, in the NEET examination conducted in 2017, 30% of candidates appeared from schools affiliated to Central Board of Secondary Education (CBSE) qualified while only 5.3 % of candidates from TNBSE-affiliated schools qualified. In a bid to react to the emerging situation, the government of Tamilnadu embarked on a mission to revise the school education curriculum for standards 1 to 12 by 2020 (TN Gov 2017a) and tasked it to the Tamil Nadu State Council of Educational Research and Training (TNSCERT).

Reform process

TN educational bureaucracy combined both movement-building tactics and the conventional tools of executive power initiating the reform. Even while the government had constituted a Curriculum Development Committee (TN Gov 2017b) and reconstituted (TN Gov 2017c) the High-Level Committee for revamping School Education, earnest effort was made to recruit administrators, educationists, policymakers, teachers, NGOs, public intellectuals, writers, poets, environmentalists and scientists from Tamil Nadu and educational experts from all over the country including representatives from union government agencies “to collect views from cross sections of the society on the changing dynamics of the school curriculum.” (Government of Tamil Nadu 2017d, p.5) (See his document for a detailed description of the various efforts made to reach out to various stakeholders).

Development of revised textbooks

Deviating from the earlier practice of resorting to few hand-picked teachers/writers, the reform process of 2017 involved a considerable number of teachers and experts, drawn widely from diverse educational boards, in the authoring of the chapter contents, writing, design and development. Extensive interaction marked the development of the chapters, and often, the texts were sent for external review. Along with various boards in India, the science curriculum in Indonesia, Cuba, Malaysia were examined. The textbook writers were also encouraged to consult CBSE, Kerala, Karnataka, and Andra Pradesh textbooks. Further, the textbooks content, treatment and presentation of Singapore, New Zealand, South Africa, Nuffield Foundation and the textbooks prepared by the Eklavya, Bhopal were consulted in designing the content, treatment and presentation of the chapters of the textbook.

Features of the revised textbooks

Instead of viewing textbooks as the ultimate repository of knowledge, the policy strive was to make it a “window to the world of wisdom” (Udhayachandran 2019, p6). On the one hand features such as case studies, infographics, concept maps, reference books and on the other ICT like QR codes were used to take the textbooks beyond the conventional garb, while on the other hand teaching-learning was to be radically changed by “shifting the focus of the science classroom from content knowledge towards critical scientific inquiry” (TNSCERT 2017a, p. 4).

Instead of “merely privilege[ing] factual knowledge”, simple episodes from the history of science (discovery of air as a mixtures of gases; history of the models of atoms) were used to provide an “understanding of how we arrive at such knowledge, critical inquiry into potential explanations of phenomena and dialogues in science” (TNSCERT 2017a, p.4). Simple expository models in science, such as particulate nature of matter, ray diagram of light were presented to make students’ appreciate how science has been able to go beyond the appearance and give us an interlinked and universal perspective on complex and diverse phenomena of the natural world . A novel feature, info-box providing inspiring information in the form of ‘do you know?’, were incorporated to ‘nurture the natural curiosity’ (TNSCERT 2017b,p.3).

Further, to give a cohesive picture of science presented in the upper primary level, the concepts, topics were sought to be organised into five major overarching themes: diversity, interactions, cycles, systems, and models. The theme ‘diversity’ was linked to the idea of ‘classification’ and diversity in life, ecosystem, diversity in the chemical elements, physical properties of matter, chemical composition were highlighted. The idea that ‘change’ occurs due to some form of interaction was presented by linking, the interaction of bodies under collision, interaction of magnetic materials, interaction such as between the environment and public health, interaction of acid and bases, the interaction between habitat and the organism and predators. The digestive system, the circulation of blood, the reproductive system in flowers, electrical systems (circuits) are ‘systems’, while the oxygen-carbon dioxide cycle between plants and animals, biodegradation, and the water cycle exemplify cycles.

To give one example of the themes, models are one of the vital aspects of modern science, yet models are not a direct reflection of ‘reality’, but idealised mental constructs that help in predicting behaviour to an extent. With the model of a ray diagram and using the concomitant geometrical optics, it is possible to predict the behaviour of the images formed under simple lenses. Likewise, the model of the particulate nature of matter enables us to predict outcomes such as the effect of heat on solids and fluids.

The principles of curriculum revision and/or reorganisation ultimately have to be absorbed by teachers who transact the new textbooks. How did teachers view the whole exercise?

BUREAUCRATIC PRACTICES AND TEACHER BELIEFS

Some quotidian practices followed by the educational bureaucracy significantly modulated the teacher beliefs about the goals, aims and purpose of the reform.

The spectre of NEET examination

The spectre of the NEET examination significantly influenced the reform process all through its course. As Udhayachandran (2019), notes in a recent article “textbook revision assumed the proportion of a major reform in Tamil Nadu mainly due to the National level Entrance Test (NEET) trigger” (p. 6_). He also cautions “while it would be improper to design a curriculum only to satisfy the dynamic and commercial needs of any test, one cannot afford to ignore the concerns arising out of such demands” (p. 6_). Although the upper primary textbooks have no direct link to NEET, the ‘teacher belief’, emanating from the broader social perception about the NEET legacy of the 'reform' influenced the teacher's views. Hence 'exam oriented' presentation formats such as 'bullet points for ease of memorisation and recall' were often insisted upon.

Content audit of the revised textbooks

One would have expected the syllabus, and the content and treatment of the chapters of the textbookto evolve from the concerns and desires expressed in the 'Tamil Nadu Curricular Framework 2017: A statement on Science Curriculum' (TNSCERT 2017a), and the 'Position paper on science: a detailed study' (TNSCERT 2017b). However, in practical terms, the driver was the outcome of the 'gap analysis' between the old TN textbooks and that of CBSE and neighbouring states like Kerala, Andhra and Karnataka undertaken by the TNSCERT. The 'gap analysis' revealed very little difference in the syllabus and content, but highlighted that the TNSBSE textbooks had only 'knowledge-based questions', while the CBSE textbooks had considerable NEET type 'application-based questions'. The revision of textbook units became an exercise to ensure adequate 'application-based questions' and that there are no 'gaps' between the revised textbook and the CBSE textbooks. When the first set of the textbooks came out the touchstone of the evaluation was the NEET examination. T. Udhayachandran said "comparison between the content of the new textbooks and the recent NEET question papers and found that almost 50% of the questions were from the Plus One portion. We checked whether those questions are reflecting what we have incorporated in the new textbooks and found that it was 100% in physics and 99% in botany and zoology" (Sujatha 2018,). Rita John, a domain expert involved in the textbook development noted that "while the old syllabus covered only 35% of the questions of the NEET syllabus and lacked application-oriented questions ... all most all the questions of the NEET 2019 were covered by the revised higher secondary textbooks" (Raghu Raman, 2019,). These quotidian practices further reinforced the 'teacher belief' about the 'goals' of the reform was to 'train' students for NEET.

TEACHER BELIEFS ABOUT CLASSROOM INTERACTIONS

'Moral obligation' and 'duty' of a teacher

Although the policy percepts described teachers as a 'stakeholder' and an 'agency' (sic), that was not the self-perception. Except for a vocal few, most teacher-experts were passive and remained mute to the discussions about the goals and aims of reform. On the other hand, textbooks, seen as the sole organiser of the classroom interactions, saw vociferous engagement from otherwise docile teachers. Does this hesitation for engaging with policy and curriculum imply dissent or resistance?

The passiveness, it could be discerned, did not arise from fear of the authorities, but rather how they viewed their own place at the table. The mental model, one could discern, was that an educational edifice is a giant machine, and they, teachers, are mere 'cogs' with a specific domain of operation. Most teacher-experts viewed the shaping of the vision, policy, and curricular framework as the 'duty' of the education bureaucracy; their own role is limited to content and treatment of textbooks and classroom practices. This perceived division of labour, subtly implied that the vision, policy and curriculum are pious statements having only ceremonial value with no real import. It is the textbooks that determine the classroom practices.

The teachers used two distinct words – 'duty' and 'moral obligation' to describe their role. Adhering to the 'instructions' such as that the classroom interactions must be 'constructive', is a 'duty', irrespective of their views on the same. However, the 'moral obligation' of a teacher is 'educating the student', often understood as training the student to commit to memory parts of the textbooks, and preparing him/her for 'examinations'. In this frame, the demands of the new policy, such as 'activities', 'projects', 'collaborative learning' were not seen as 'new ways of teaching/learning', but as a set of 'instructions' from Education Department, that they are duty bound to follow. Although most of them agreed that children should be motivated to do classroom projects, they saw it as a stratagem to entice students to the memorisation regimen rather than a radically new way of teaching-learning.

Disquiet about Inquiry pedagogy

The vision statement TNSCERT (2017a) expects every school to be a place where "children learn to ... engage in data collection, tabulation and discuss their interpretation.. [and]...design and perform simple experiments of their own, and argue the outcomes" (p. 8). The notion that students collect data, tabulate them, 'discuss their interpretation' and 'argue the outcomes' of experiments goes much beyond 'tabletop', or 'hands-on' experimental demonstrations by the teachers.

The demand for demonstration of experiments, at times, may be resented on the grounds of lack of time and 'workload'. Nevertheless, the teachers are comfortable with them. The demonstration, even data collection and tabulation are 'governable', as the results are pretty much anticipated, pose little challenge. However, the contours of 'dialogue and discussions' are uncertain. The prospect of 'un-governability' of the discussions, as well as the potential humiliation it can cause, mortifies, even terrifies the teachers.

Although corporal punishment is sometimes used to 'discipline', it is 'control' that concerns teachers. Often' control' of the classroom is insured through the respect, esteem and reverence teachers command. Without 'control', the teachers feel that they will not be able to fulfil their 'duty' and 'moral obligations'. The perceived and implicit hierarchy of knowledge provides the 'reverence and esteem', while the power to admonish and punish gives them the authority. Anything that threatens or destabilises these twin 'powers' in the classroom is seen as a threat.

Furthermore, the all-pervasive 'textbook culture' also undermines and seeds doubts on the efficacy of 'dialogue and discussion' for instruction. Kumar (2005) says that the textbook culture treated the "prescribed textbook as the de facto curriculum, rather than as an aid, the teacher taught the text by elucidating it, by asking children to copy and memorise it, and finally by drilling them to answer and memorise questions that were based on it" (p. 67). Thus the textbook dominates the classroom, and neither teacher nor students wish to digress from it. If something is not elaborated in the textbook, then such activity finds no place in the classroom. Conversely, if some text is written, the 'text' itself becomes an object to be 'taught' defeating the purpose of the inquiry.

Mental image of science and nature of science

The curricular framework for science (TNSCERT 2017a) says, "At the upper primary stage, the emphasis has to be on what constitutes the process of science, its distinct way of building knowledge" and the classroom process must have "fundamental commitment to experimentation and verification ... gathering data and information systematically ... learning to interpret data ... model building and exploration of how things work" and that the "structure of science is also introduced at this stage" (p.7).

The actualisation of this percept implies a particular understanding of the nature of science. A recount of the discussion on the preparation of a chapter on 'health' would illustrate how the teachers viewed 'science'. The draft text reads "Consider malaria, anaemia and the injury resulting from falling. All these are an illness of one kind or other. Are they all the same? Often common cold may spread from one member of the family to another. However, anaemia does not spread from one patient to another. Those diseases that can spread from one to another are called infectious diseases. Non-Infectious diseases do not spread from person to person. They have other causes. While ... are examples of infectious, and ... are examples of non-infectious diseases." (TNSCERT 2018, p.1).When the teachers edited it, the revised draft was typical of 'kunji' catechism style. It read "The prevention and treatment of sickness can be considered in two groups for their better understanding. They are, communicable and non-communicable disease" . Examples of infectious diseases are ... and non-infectious diseases are ..." (Department of school education 2019, p.87) Why should we 'group' the diseases? How does such a classification help? However, it can be seen that the revised text readily lends itself to set questions like 'diseases are classified into ....', or 'give three examples of non-infectious diseases'.

Why should one accept assertions made in the textbook? A discussion during the preparation of a chapter on tropism may illustrate the ingrained view of the nature of science. The first draft of the chapter read: "Roots during the germination display a tendency to grow downwards, while shoots grow upwards and this is an example of tropism. This tropism is called Gravitropism" (TNSCERT 2017 d, p.5)). The teacher-experts were baffled when questioned; 'is it root or shoot or both that sense' gravity'?', 'How do you know that the factor that is involved is 'gravity' and not any other factors, say light?' 'What happens when you try to grow a plant in say, space under microgravity conditions?'. We decided to include a small section on 'how we know what we assert' to give a historical overview or provide some evidence for some of the claims asserted in the textbook. However, more often such narrations were edited to bullet points giving information that such and such scientist from such and such country did an experiment during the year so and so that 'proved' the claim. It was evident that teachers often viewed the presentation of 'school science' to be 'authorised' piece of information and not necessarily something that demand 'appeal to reason'. Once again 'knowledge' was seen as 'authoritative', in a sense, accumulated, attested and transferred by 'authorities'. In this frame everything said in the textbooks becomes unquestionable 'facts' and 'truths', leaving little scope for individuals or a group of children constructing their knowledge through exploration, experimentation, dialogue and rational discussion.

TEACHER BELIEFS ABOUT SOCIAL JUSTICE CONCERNS

Socio-historical factors such as caste discrimination, the colonial legacy of modern educational institutions have resulted in social stratification in Tamil Nadu, as is the case elsewhere in India. Osborn, Broadfoot, Planel, and Pollard (1997) observe in addressing the issues of educational opportunity, social disadvantage and inequality, strategies used in France and England are typified by what he calls as ‘universalistic norm’ and ‘differentiated approach’. Universalist norms “provide the same curriculum and pedagogy to all pupils regardless of who they are, where they live or even, within limits, of their ability level” (Osborn et al., 1997, p.377), while the ‘differentiated approach’ approach demand that the classroom must take into account the needs and the socioeconomic characteristics of the local environment and pupil.

In TN, the public discourse is heavily influenced by the republican values and social justice paradigm, and any talk of ‘differentiated approach’ is anathema. On the other hand, the social arrangements for differential schooling, reproducing the social iniquities, were accepted. TNSBSE used to have multiple school boards until 2009, until the single ‘samacheer kalvi’ (uniform education) was adopted in 2010. However, at the national level multiplicity of national boards, such as CBSE and ICSE, persists. Teachers viewed the existence of multiple boards, as reflecting the students’ potential rather than an institutional arrangement that reproduces social stratification. When the first set of the revised textbooks came out, a domain expert stated “We have set new standards for the students. The concern was whether rural students would do well” (Sujatha 2018). The revised textbooks were criticised for being ‘voluminous’ and ‘heavy’ for TNSBSE affiliated schools. The contradiction of the normative ‘universalism’ and the practice of ‘differential’ education was not easy to resolve.

DISCUSSION

Will the revised textbook, syllabus and curriculum make a change in the classroom interactions? The reform policy of 2017 states that “realising these changes requires empowering teachers by providing them with a range of educational resources ... providing teachers’ guides for each textbook, building teachers’ portals for knowledge sharing, training teachers in technology use, especially ICT enhanced pedagogy” (TNSCERT 2017a p.9). Thus the policy looks at the teachers as ‘implementer’ and ‘teacher preparation’ as providing necessary teaching resources.

As Fullan (2001) observes “implementation is the essence of change, it follows that the teacher as implementer is central” (p. 8).However, with teachers predominantly viewing ‘knowledge’ as merely ‘authorised’ piece of information, as Clarke (2003) notes “knowledge continues to be ‘given’ ... learning continues to be based on repetition” (p. 37-38). The cultural constructed-ness of teacher thinking and teaching results into “embeddedness of practice and its resistance to change” (Clarke, 2003, p. 29). For productive school reform, ‘reculturing teachers’ to the central tenets of the reform is imperative (Fullan, 2001, p. 8). Without mindset change, despite the improvements and innovations in the revised textbook, classroom practice may not see much-desired change.

Pathmarajah (2014) observes that state bureaucracies, entrenched in a behaviourist mindset, often produce a specific normative discourse about educational procedures, routines, and tasks that construct teachers as technicians of administrative labour, students as passive and neutral, and learning as memorisation and thus frustrate and undermine the constructivists’ educational reform. Nevertheless, as Niesz and Krishnamurthy

(2013) observe, activist-administrators, at times, have successfully "used traditional tools of bureaucratic power, including top-down mandates, to institutionalise the reform" (p.29_), the 'movement-building tactics' generated the 'egalitarian spirit', 'moral authority and goodwill' ensuring the mindset change among teachers leading to change in classroom practice.

Although criticised for being top-down, bureaucratically imposed, limiting teacher's autonomy, and feared to have brought uniformity and rigidity in the classroom, the Activity Based Learning (ABL) initiative was able to transform the mindset of the teachers, by consciously forging a network of "social agents from across multiple fields of practice, including participants of literacy and science people's movements, educators from progressive NGOs and elite schools, and state administrators" (Niesz et al., 2014, p.163).

During the ABL initiative, "people's movements and progressive education initiatives ... [formed] an influential network" and engendered a "counter-hegemonic education knowledge, that ultimately transformed classrooms in over 37,000 schools" and "positioned the government schools to lead (rather than follow) social change" (Niesz & Krishnamurthy, 2014, p.163). Niesz and Krishnamurthy (2014) point out that the "convictions that, on the one hand, every child can learn and, on the other, children are equal irrespective of their success on school tasks were clearly at odds with what we heard about conventional views of learners in the government schools" (p.158). The 'failure' of the child was not dismissed as a reflection of the limitations of the 'innate' capacity of the child, but called for suitable approach particular to the child. Although student performance in literacy and numeracy did not show significant increase, children in ABL schools were less reliant on their teachers, more likely to seek help from peers, had more faith in their abilities to solve difficult questions themselves, were more confident, and had more positive inclination in their abilities to cope with exams and schoolwork. (Akila 2011; SchoolScape 2009; Singal et al. 2017).

The 2017 reform initiative too began with activist-administrator(s) roping in various social segments. The policy note, curriculum framework and syllabus were shaped with the involvement of massive participation. However, within a few months of the launch, the state government shifted a key official leading to the waning of the 'activism', and the reform became yet another bureaucratic top-down dictate. Once again, the teachers were seen as 'implementers' and relegated to the periphery of the reform. The reform lost touch with the broader network, and the agenda of reculturing teachers lost its steam. Hence one fears, despite the revised textbooks, syllabus and curriculum, the actual classroom practice may not see much significant change.

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METAPHOR-EQUIPPED TEACHING OF LINEAR ALGEBRA

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The article presents a study about using metaphors or analogies as a tool to illustrate some introductory concepts of linear algebra. It conducts a brief survey in an attempt to explore the effects of metaphors in teaching linear algebra and with that it argues in favor of equipping the teaching of formal mathematics with metaphors used in real life. At the same time the article acknowledges the presence of potential pitfalls of metaphors and with illustrations, suggests ways to minimize them using the FAR guide.

INTRODUCTION & LITERATURE REVIEW

"New ideas come from old ideas that are revisited, reviewed, extended, and connected" (Maher, 2010). If an advanced topic in a mathematics classroom is connected with previous knowledge, it is likely to ease the problems of a lot of students, struggling with abstract concepts of the subject (Gentner, Holyoak & Kokinov, 2001). The new knowledge should be constructed from experience and prior knowledge, otherwise it causes fear of mathematics among children (NCERT, 2005; NCTM, 2000).

To make connections with a previous knowledge, teachers adopt an instructional approach of employing nonmath analogies or metaphors (Sarina & Namukasa, 2010; Richland, Holyoak & Stigler, 2004). Using an analogy or a metaphor means understanding a situation in terms of the other. Many times, it offers linking or comparing the abstractions in mathematics with simpler and more familiar ideas. "Many of the most fundamental mathematical ideas are inherently metaphorical in nature" (Lakoff & Núñez, 2000). Sfard (2008) describes metaphors as generators of new discourses. Thus, the technique of associating metaphors should not be seen as artificial.

Frant, Acevedo, and Font (2006) examine how teachers use metaphors while teaching graph functions in a mathematics classroom. Richland, Holyoak, and Stigler (2004) identify analogies in a random sample of eighth-grade mathematics classrooms. They analyze patterns of teacher-student participation, analogy source and target constructions, and contexts for analogy constructions. There is a paucity of research examining the influence of metaphors in teaching and learning linear algebra. Adiredja and Zandieh (2017) reveal how eight women of color understand the concept of basis in linear algebra using intuitive ideas from their daily lives. Sweeney (2012) offers a travelling metaphor and its impact on reasoning in linear algebra.

The present article investigates how metaphors or analogies can be used as a device to illustrate some basic concepts of linear algebra. It carries out a survey which aspires to find the effects of metaphors in teaching linear algebra and with that it argues in favor of equipping the teaching of formal mathematics with metaphors used in real life. Further, it attempts to underscore the significance of the following questions in relation to linear algebra: Do metaphors generate new knowledge or are they just excellent communication tools (Harrison & Treagust, 2006)? How much control does a teacher have over his/her metaphor usage? Does the teacher know the positive/"negative" effects of metaphors in the negotiation of meaning (Richland, Holyoak & Stigler, 2004)? How to keep down the "negative" impacts of metaphors, if any? Can a *single* analogy suffice for a concept? These questions come to the surface substantially when the survey finds some alternative conceptions of the metaphors among the students. The article aims to consider some techniques to reduce the "negative" effects of metaphors while dealing with these questions.

THEORETICAL FRAMEWORK

An abstract unknown domain is conceptualized in terms of some concrete familiar domain. The former is called the target domain, and the latter is called the source domain. We are familiar with the source domain but not so with the target domain. The source domain serves as a source of knowledge about the target domain, that we want to investigate. A metaphor "A is like B" is a mapping $m: B \to A$ from B to A, where B is a source domain and A is a target domain (Lakoff & Núñez, 2000; Gentner, 1983). The metaphor m sends entities in the conceptual domain B to corresponding entities in the other conceptual domain A. The inferential structure of the familiar domain guides students to "argue" about the unfamiliar domain.

While teaching through metaphors, students' personal construction of meaning may differ from the teacher's intended knowledge (Harrison & Treagust, 2006). To minimize these "disadvantages" of a metaphor, Treagust, Harrison, and Venville (1998) offer a set of steps: the Focus-Action-Reflection (FAR) guide. The first stage of Focus involves a pre-lesson activity of thinking if a concept to-be-taught is difficult for the students, and then an analogy is generated by the teacher. After that, in class, the degrees of likeness and unlikeness of the analogy with the concept is checked in the second stage of Action. The last stage of Reflection involves a post-lesson activity of modifications or changes in the analogy. The modifications may come in terms of replacement of the analogy, multiple analogies for a single concept, or else (Harrison & Treagust, 2006). The FAR guide goes through iterations to evaluate and qualify the metaphors so that they serve well in teaching and learning.

METAPHORS

This section proposes metaphors for some introductory concepts of linear algebra. The following metaphors may seem naïve, crude and simple for someone, but are likely to be very helpful. For definitions, please see some standard text of linear algebra (Friedberg, Insel & Spence, 2003).

1. The linear combination of vectors is like a mixture of things.
2. The span of a set in a vector space is like a collection of all mixtures of things. If $\alpha \in$ span S, then α is a mixture of some vectors in S or α can be made from vectors in S.
3. A set S is called a spanning set (SS) of a vector space V, if it spans the entire V. In other words, if S

is a spanning set of V then every vector in V can be made from vectors in S, or we can say the set S can make any vector of V, or S has shortage of nothing. A spanning set has no shortage, so it is also like a person who is rich.

4. A set S in a vector space V is linearly dependent (LD), if and only if there is some vector v in S which is a linear combination of other vectors in S, or there is a vector v in S which can be made from other vectors in S. If this v were not in S, still it could have been made from other vectors in S, so let us call such vector v as redundant vector in S. An LD set is like an object with a redundant thing.
5. A linearly independent (LI) set S in a vector space V is like an object in which nothing is redundant, or it is like a person who is poor.[1]
6. Suppose a child gets pocket money from his/her parents. The child thinks that there should not be shortage in the pocket money and simultaneously the parents think they should not give any redundant money. To make both the child and the parents happy, there should be neither shortage nor redundancy in the pocket money. In other words, the money (regarded as vectors, for a while) should be an SS as well as an LI set. In such an ideal situation, the set is called a basis. A set B is said to be a basis of V, if it is linearly independent and a spanning set of V. A basis is like an object with no shortage, and has no redundant thing.

The following table recapitulates the above metaphors, which were mainly told to the students.

Source Domain	Target Domain
Mixture of vectors	Linear combination of vectors
Collection of all mixtures of things in S	Span S
S has shortage of nothing (rich)	S is a spanning set
At least one redundant vector in S	S is linearly dependent
No vector in S is a redundant vector (poor)	S is linearly independent
An ideal situation (no shortage & no redundancy)	Basis

Table 1: A recap of metaphors stated above

METHOD

The survey participants were 76 students who had just passed grade 12 final exams from various schools in Bihar, India, who were called together with the help of a teacher. They were introduced by the author (who met them for the first time) to some introductory concepts of linear algebra not by formal definition, but via the metaphors given in the previous section, in five half-hour classes. In initial classes, some hands-on sheets were discussed to make them familiar with these concepts. Then, in the final class, they were surveyed through a series of questions. The Fill-in-the-Blank and True-and-False questions first motivated them to write a *source domain statement*, in their native language Hindi, about the source domain, and next to it, write an analogous *target domain statement* about the target domain. After the questionnaire, the students

[1] (Some of my known persons rose objection saying poor among students dishonorable). I still want to keep it for quantitative purpose only, at least for the time being.

were divided in four equal groups and informal verbal discussions followed separately with each group. In this way, the survey tested if the students were capable of making intended conjectures about the target domain, without having been introduced to formal definitions. Although linear algebra is an undergraduate course, the survey participants were students, all of whom had just graduated grade 12, and none of whom had studied linear algebra earlier. To be clear, the purpose of the study was not to introduce the topics to school students. Showing the effects of metaphors-alone, the study was conducted on students, who had not studied linear algebra earlier, and the "positive outcomes" of the study convince us that if undergraduates are introduced to formal definitions accompanied by analogies or metaphors, it would be likely to help make learning more sensible. The responses of the students which are subjective in nature were analyzed collectively (on request) by two professors to determine the efficacy of the method, and other possible advancements, along with identifying "faults" in it. The application of the FAR guide is urged to fix those faults in the later sections.

TASKS

A questionnaire (originally in Hindi-cum-English language), that was given to the students, is provided in this section. The blanks, which were empty originally, are filled below with the desired answers. The initial blanks motivated them to write a statement from a source domain, then the final blank in each question is about the intended conjecture, that the participants were expected to fill about the target domain. There are some assumptions mentioned below, which were thought not important to be told to the participants during the survey.

QUESTION 1

Let $X \subseteq Y$ (see Figure 1). Suppose X has a redundant thing (vector) u. Fill the blanks below.

a) X has a redundant vector $u \Rightarrow$ X is LD.

b) Does Y have a redundant vector? Yes.

c) What type of set Y is? Y is LD.

If a "smaller" set has a redundant thing, then a "bigger set" also has a redundant thing (referring bigger set to superset, and smaller set to subset) (*source domain statement*).

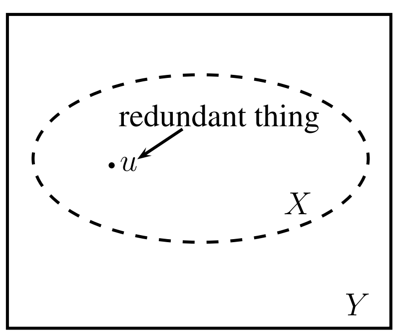

Figure 1

Intended Conjecture: <u>A superset of a linearly dependent set is linearly dependent</u> (*target domain statement*).

QUESTION 2

Let $X \subseteq Y$ (see Figure 2). Suppose Y has no redundant thing.

What statement would you like to propose? Fill the blanks below.

If a "bigger" set has no redundant thing, then <u>a smaller set also has no redundant thing</u> (*source domain statement*).

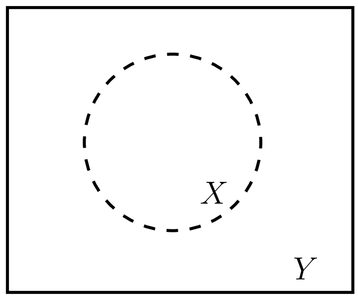

Figure 2

Intended Conjecture: <u>A subset of a linearly independent set is linearly independent</u> (*target domain statement*).

QUESTION 3

Let S be a nonempty subset of a vector space V (see figure 3). Suppose S has no redundancy. The figure shows the "region" of span S, encircled by the oval bold boundary, containing S The rectangular region shows V. Fill the blanks below.

(a) What type of set S is? <u>S is linearly independent</u>.

(b) Which vectors can be constructed from the vectors of S? Dark the region containing those vectors.

(c) Seeing the figure, fill the blank ahead such that the set $S \cup \{u\}$ has no redundant vector. What type of set this is? <u>$S \cup \{u\}$ is also linearly independent</u>.

(d) If S has no redundant thing, and if <u>α is not an element of span S</u>, then $S \cup \{\alpha\}$ has no redundant thing (fill the blank with details about the whereabouts of α) (*source domain statement*).

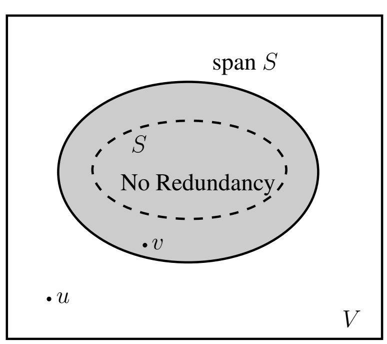

Figure 3

Intended Conjecture: If S is linearly independent and $\alpha \notin$ span S, then S $\cup$ $\{\alpha\}$ is also linearly independent (target domain statement).

QUESTION 4

Fill the blank below:-

Cost of a Rich person's total property ≥ Cost of a poor person's total property (although there is a technically error, see assumptions below) (source domain statement).

Assumptions: There are two assumptions. Firstly, the cardinality of a spanning set and a linearly independent set can be same, for instance, a basis of the space, but we do not find much harm not laying stress on it among the participants, because this model is de facto for undergraduates, who would complete the argument that card (an SS) ≥ card (an LI set), once they know formal definitions. Secondly, we are working in a finite-dimensional vector space, although card (an SS) ≥ card (an LI set) holds in every vector space, once Zorn's lemma is invoked (Bourbaki, 1974).

Intended Conjecture: The cardinality of a spanning set > The cardinality of a linearly independent set (target domain statement).

QUESTION 5

The top box (set) in the Figure 4 is an SS and an LD set. This set must have some redundant vector, which is thrown out to get a smaller set, shown just below the top. The smaller set must be an SS because throwing out a redundant thing, would not lead to any shortage. Suppose it is LD, as shown. The same thing we do with it as we did with the set at the top. It is repeated until we get a set first time with no redundancy. This set represents an ideal situation. Below it, all are LI sets, and above it, all are SS.

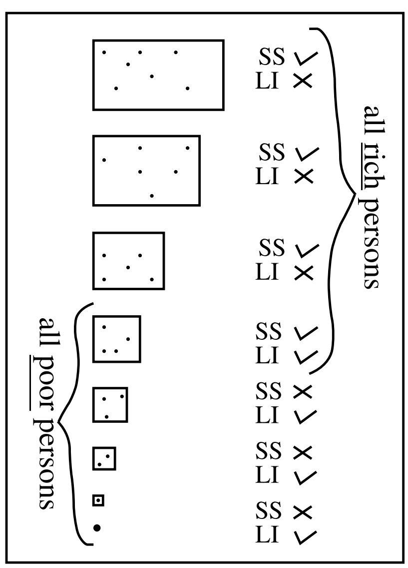

Figure 4

(a) Fill the two blanks (aside the brackets) in the figure about the type of persons above and below the ideal situation (basis).

(b) What type of rich is the ideal-situation-box with respect to other rich? Fill the blank ahead. The rich person in the ideal situation is less rich than other rich (although it is technically wrong, see assumptions below) (*source domain statement*).

Assumptions: There are two assumptions. Firstly, for the time being, we consider no difference between a minimal element and a minimum element of a poset. Secondly, we assume Zorn's lemma, so that we can say an arbitrary vector space has a basis.

Intended Conjecture: A minimum (or minimal) spanning set is a basis (although it is technically wrong as there need not be a unique minimal spanning set, see assumptions above) (*target domain statement*).

FINDINGS

The responses of the survey participants were evaluated to see if they make some progress towards the intended conjectures. Their responses might contain naïve words, they may not be able to write the conjecture in a complete formal code, they may make grammatical errors, the evaluation ignores them all, and seeks to address if the responders intuitive answers are satisfactory, partly satisfactory, wrong, or unintended replies.

Even though there are a significant number of responders who could not reply satisfactorily for each question, the large number of responders who replied satisfactorily seems to show the magic of metaphors-alone (see table 2). One is likely to believe, if undergraduates are introduced to formal definitions equipped with these metaphors, it makes a big impact on their understanding.

Q. No.	Satisfactorily attempted responses	Partly satisfactory attempted responses	Wrong responses	Un-attempted or Undesired responses
1	58	2	4	12
2	57	2	2	15
3	59	11	2	4
4	61	2	2	11
5	54	1	0	21

Table 2: Evaluated responses to the questions

As per FAR guide's second step of Action, wonderful replies were collected from the participants, which are worth mentioning. For the fourth question, two responders stepped even ahead of the intended reply, adding that the cardinality of a spanning set may be equal to that of a linearly independent set. The last question's responses are relatively more impressive; a basis is a needy rich, a basis is less rich than the other rich (technically it is not correct, because there are more than one minimal spanning set), a basis is a less-sized spanning set, to mention just a few. For the third question, one participant wrote conversely that "If S is independent, and $S \cup \{\alpha\}$ is also independent, then α comes out of span S". Some responses to the third question were unanticipated. In the Fill-in-the-Blank (d) of question 3, one wrote that if S has no redundant thing, and $\underline{\alpha \text{ comes from S}}$, then $S \cup \{\alpha\} = S$ has no redundant thing. Some even wrote, $\underline{\alpha \text{ does not exist,}}$ so that $S \cup \{\alpha\} = S \cup \varnothing = S$ has no redundant thing. While discussing, a student said, {tea leaves, sugar, milk} may be regarded as a basis for making *chai*." Further, it turns out students discussed the proportions/ mixture of each of them to make *chai* of particular taste. If the proportion is changed even a bit, the taste changes. Essentially, an important result that, "Each vector can be written *uniquely* as a linear combination of basis vectors" was being discussed. During the discussion, it was easy to explain in terms of redundant vectors why the empty set $\varnothing$ is an LI set.

A metaphor must be chosen very carefully for a concept. A "wrong" metaphor may be misleading. It may also happen that a metaphor is useful for one person, but not for some other person, as recorded here. For the third question, when asked to darken the region with vectors that can be made with the vectors of S, many respondents darked only (span S) \ S. When asked the common reply was that the vectors of S are already there, we need not make them. The metaphor may have misled them not to consider $S \subseteq$ span S. One responder wrote that if S has no redundant thing, and $\{\alpha\}$ is linearly independent, then $S \cup \{\alpha\}$ is linearly independent. When asked he said that the union of two linearly independent sets is linearly independent, because none of the two sets have redundant things, so their union does not have any redundant things. However one of his fellow friends fixed the bug, saying "Suppose one person has a glass of milk and a packet of sugar, and another person has a packet of tea leaves and a packet of sugar. Both want to make *chai*. They can make it only collectively, and then one packet of sugar would be redundant." One responder replied for the first question that if a smaller set has a redundant thing, then that thing may be essential for the bigger set. This reply is exactly opposite to the intended reply. When I asked its elaboration, she said, "Suppose we bought a new TV set for our house, because we are bored of watching the old TV set. The old TV set is redundant in our house. It may happen, someone in our colony does not have any TV set, and if we give the old TV set to that person, it won't be redundant for him/her. Thus a redundant thing in our house need not be redundant in our colony." During the discussion, a student said, "In set $\{a, b, c, d\}$, if a is redundant, and $\{b, c, d\}$ is LI, then a is the only redundant element, so *only* subsets of $\{b, c, d\}$ are the LI subsets of $\{a, b, c, d\}$." This need not be true! The last two alternative conceptions are dealt with again in the next section for the last stage of the FAR guide.

CONCLUSION

The findings reveal that metaphors may act as a pertinent tool for making classroom learning more meaningful, and contextual, so the students are likely to reinforce their thinking capacities and construct meaning of the concepts based on their own experiences. The findings also reveal that the use of metaphors has another side also; there are advantages, but also "disadvantages."

We encountered students' various alternative conceptions in the last paragraph of the Findings section. The last two of them are worthy to discuss, as an illustration of the last stage of Reflection. For the second last alternative conception in the previous section, we can search for some other metaphor, like saying a blend-of-other-vectors-in-the-set, instead of redundant vector, which probably helps in overcoming the problem. For the last alternative conception, a traditional list of most basic human needs for life is food, shelter and clothing. Suppose there is a person who has all of them. Assume his/her shelter is a small hut. If someone offers him/her a big house, then which of the two shelters is redundant? Small hut or big villa?! It depends on the person's desires. We are more interested in knowing that if one thing is redundant than which one is redundant. We are concerned with the number of redundant things. Further, the number of redundant things in an SS can easily be related to the dimension of vector spaces. As discussed earlier, due to social discomfort, we may avoid using the term "rich-poor", or if used, our intention should be clear among the students that these are used just for a quantitative purpose only.

"Multiple analogies are better with each analogy selected for the concept it explains best" (Harrison & Treagust, 2006). As an illustration, we can use multiple analogies for LI sets; one with view of redundant vectors, and one with of blend-of-other-vectors-in-the-set. The former helps in explaining question 5 of the questionnaire, while latter may be more helpful for question 1. Caution should be exercised because of the limitations that metaphors pose when over generalized. "Of course analogies have to be used very carefully, thoughtfully and always, always, always as a side dish to the main course of mathematical reasoning" (Sarina & Namukasa, 2010).

To wrap it up, the article talks about the research questions raised in the introductory section in relation to linear algebra through various stages of the FAR guide, and it further envisions an extension of the metaphor-linking based research of linear algebra, research that includes determining various metaphors and their limitations through empirically collected data for more advanced topics (Sweeney, 2012).

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MATHEMATICS TEACHERS' TECHNOLOGY INTEGRATION SELF-EFFICACY AND TECHNOLOGY USE

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Technology integration self-efficacy plays a great role in determining teachers' use of technology in teaching. This study investigated the association between mathematics teachers' use of technology and their technology integration self-efficacy. The study employed a survey design and 125 mathematics teachers participated in filling the questionnaire. Data analysis was done descriptively and inferentially and processed using Statistical Packages for Social Science version 20. Independent samples t-test and effect sizes were used. Despite teachers reporting to have a moderate level of self-efficacy, the study found a significant association between technology use and self-efficacy in technology integration. However, very few teachers reported using technology for instructional purposes. The study recommends that developing teachers' self-efficacy levels and facilitating their actual classroom technology integration may be important in enhancing technology use in mathematics education.

Keywords: *self-efficacy, technology integration, technology use, mathematics education, technology literacy*

INTRODUCTION

The increasing availability of technology especially in education has increased teachers' need to integrate them into their teaching. The need has increased with the evidence that supports the view that educational technology has the potential to transform teaching practices (Kartal & Çinar, 2018). There is evidence from the literature (Durak, 2019; Farjon, Smits, & Voogt, 2019; Hatlevik & Hatlevik, 2018) that actual technology integration practices are highly influenced by teachers' self-efficacy in using these technologies in their classrooms. Technology competence does not readily transform into classroom use unless teachers believe that they can do so (Henson, 2002). It has been reported that teachers with high self-efficacy in technology integration are more likely to integrate technology into their teaching. Those with high self-efficacy are more likely to try out new methods and technologies in their teaching (Paraskeva, Bouta, & Papagianni, 2008). Exploring the level of teachers' self-efficacy in technology integration may facilitate efforts in explaining the extent to which teachers are likely to integrate technologies in teaching.

The concept of self-efficacy is well expounded in literature. Schlebusch (2018) explains technology integration self-efficacy as one's self-evaluation of their ability to exploit technology potential in reaching their intended goals. Self-efficacy which may also be termed as confidence in what one can do (Njiku, Maniraho, & Mutarutinya, 2019). The concept derives its origin from Albert Bandura's social cognitive theory. The theory suggests that self-efficacy determines the initiation of coping behaviour, the amount of efforts used and persistence when addressing challenges (Bandura, 1977). As such the theory explains efforts to learn new technologies and use them in new contexts even when the school environment sets drawbacks. In this line of argument, it may be suggested that self-efficacy informs the extent to which teachers are likely to integrate technology education.

Self-efficacy has been documented to be related to teachers' actual use of technology. With increasing access to technology (Mtebe & Raphael, 2018), teachers are expected to have some experience in using them. Prior experience with technology is said to influence teachers' technology integration self-efficacy. Multiple studies have reported the relationship between use and self-efficacy (Giles & Kent, 2016; Kent & Giles, 2017). In some cases, the use of such technologies in education has remained administrative rather than for instructional including preparing school announcements, reports, letters and student registration (Mwalongo, 2011). In the contexts where technology use is not translated into classroom practices (Birisci & Kul, 2019), the extent to which such uses relate to self-efficacy for instructional purposes may need to be further explored. Working with pre-service teachers, Kent and Giles (2017) report high self-efficacy in technology integration across the curriculum but low self-efficacy in actual lessons they taught. In this study, we explore the extent to which teachers' use of technology is related to their self-efficacy in teaching with technology. With the focus on mathematics teachers, we explore mathematics teachers' level of technology self-efficacy and how it is related to their technology use in teaching, lesson preparation and administration. In his study, instructional use of technology included multiple presentations of concepts using software such as GeoGebra and spreadsheets, mathematics video clips, and electronic reading resources during classroom activities. Preparation for teaching includes teacher's personal study, preparing students' notes and lesson plans. Administrative uses include preparing school announcements, reports, letters and student registration (Mwalongo, 2011).

PURPOSE OF THE STUDY

The purpose of this study was to explore mathematics teachers' level of technology integration self-efficacy and the way it relates to their use of technology in education. The study responds to the research question; what is the association between teachers' use of technology and their level of self-efficacy? The study examines three key variables; teachers' use of technology for administrative activities, lesson preparation, and instruction in association with self-efficacy in technology integration.

METHODOLOGY

The study investigated mathematics teachers' technology integration self-efficacy. The study employed a survey design where a closed-ended questionnaire was used. The questionnaire was developed by the researchers. Participants were asked to rate their self-efficacy measured using 12 items against a five-point Likert scale whereby 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agreed. The questionnaire had a reliability of á=.864 Cronbach Alpha. The sample size was 125 (80 (64%) male and 45

(36%) female) mathematics teacher from Dar es Salaam – Tanzania. To respond to the research question, three hypotheses were developed:

1. Mathematics teachers who use technology for instructional purposes have the same score in technology integration self-efficacy as those who do not.
2. Mathematics teachers who use technology for lesson preparation have the same score in technology integration self-efficacy as those who do not.
3. Mathematics teachers who use technology for administrative activities have the same score in technology integration self-efficacy as those who do not.

Data were analysed descriptively using percentages, mean, and standard deviation and inferentially using t-test and processed using Statistical Packages for Social Science (SPSS) version 20. To test the assumption in the hypotheses, we used the independent samples t-test. We further calculated the effect size for each significant difference that was detected by the t-test, where .01 = small effect; .06 = moderate effect; and .14 = large effect (Cohen, 1988).

FINDINGS

The study was designed to investigate the association between technology use and mathematics teacher's technology integration self-efficacy. Using descriptive statistics, the overall mean score level of mathematics teacher technology integration self-efficacy was seen to be moderate (M = 3.58, SD = 0.8). Some items that were used to measure teachers' technology self-efficacy are as shown in table 1. The variation of teachers' scores on the self-efficacy scale was large as indicated by the large standard deviation.

Item	Mean	SD
I am confident that I can help my students to use mobile devices to learn mathematics	3.42	1.03
I am able to type mathematics notes/exam using a word processor	3.67	1.09
I am able to use mobile technologies to study mathematics	3.72	1.08
I am able to use a computer to simplify tedious mathematical work	3.39	1.18
I can learn mathematics using computer software (e.g. GeoGebra and spreadsheet)	3.36	1.15
I can learn to use mathematics software on my own	3.42	1.12
I am confident that I can use the internet to find any mathematics resources	3.87	0.94
I can learn a lot of mathematical concepts using technology	3.73	0.97
I consider myself capable of correctly incorporating technology in my teaching	3.55	0.97

Table 1: Descriptive Statistics for Mathematics Teachers' Technology Integration Self-efficacy (N = 125)

Responding to the questions about teachers' use of technology, 14 teachers reported using technology for teaching, 86 for preparation of lessons, and 78 for administrative activities. This information is illustrated in Figure 1.

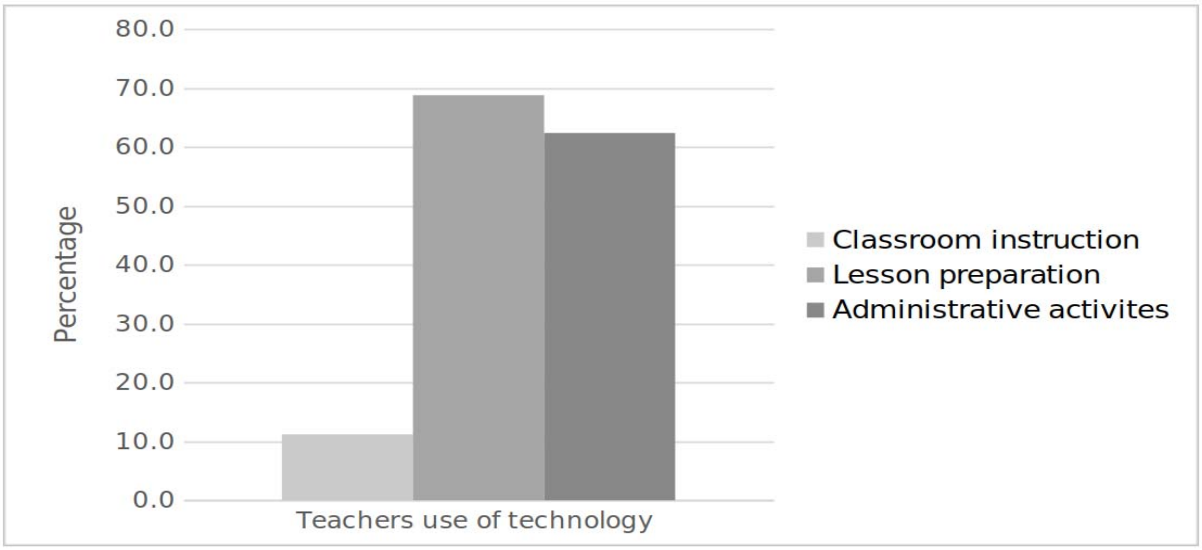

Figure 1: Mathematics Teachers' Use of Technology

In responding to the research question, the study tested the three assumptions made in the hypotheses. An independent samples t-test was used to examine if any significant differences existed between users and non-users. Furthermore, to explain the magnitude of such differences, eta squared statistic was used for effect sizes.

Hypothesis 1

Mathematics teachers who use technology for instructional purposes have the same mean score in technology integration self-efficacy as those who do not.

Using t-test, there was a significant difference in mean scores on technology integration self-efficacy between mathematics teachers who used technology for instructional activities (M = 4.34, SD = .57) and those who did not (M = 3.48, SD = .77; $t(123)$ = 4.04, p < .05). The eta squared = .12 was seen to explain the effect size of the difference between the two groups. This indicates that mathematics teachers who used technology for instructional purposes scored substantially higher than those who did not.

Hypothesis 2

Mathematics teachers who use technology for lesson preparation have the same mean score in technology integration self-efficacy as those who do not.

There was a significant difference in mean score of technology integration self-efficacy between mathematics teachers who used technology for lesson preparation (M = 3.72, SD = .70) and those who did not (M = 3.27, *SD* = .92; *t* (123) = 2.99, $p < .05$). When the effect size was calculated, an eta squared =.07 was obtained. This indicates that mathematics teachers who used technology for lesson preparation scored significantly higher than those who do not. However, the effect size explaining this difference was moderate.

Hypothesis 3

Mathematics teachers who use technology for administrative activities have the same mean score in technology integration self-efficacy as those who do not.

The mean score in technology integration self-efficacy of mathematics teachers who used technology for administrative activities (*M* = 3.71, *SD* = .77) was significantly different from the mean score of those who did not (*M* = 3.36, *SD* = .81; *t* (123) = 2.44, $p < .05$). The magnitude of this difference was explained by a calculated eta squared = .05. Despite findings showing that mathematics teachers who used technology for administrative activities scored significantly higher than non-users, the effect size explaining the difference was small.

DISCUSSION

This study was designed to investigate the association between mathematics teachers' use of technology and their technology integration self-efficacy. Using descriptive statistics, it was found that most teachers did not use technology for instructional purposes. This suggests that despite the increased access to technology (Mtebe & Raphael, 2018) teachers are still reluctant to use them in facilitating their classroom practices. However, the majority of teachers reported using technology in their personal reading as they prepare for lessons. These findings are also supported by Mwalongo (2011) who found that most teachers did not use technology for instructional purposes but rather for administrative purposes. In contrast to these findings, a study by Giles and Kent (2016) found that 93% of teachers reported to use technology in their teaching. The Tanzanian context in which this study was done would account for the low uptake of technology in actual classroom teaching as technology integration is still in the early stages.

Teachers scores on the self-efficacy scale was moderate (*M* = 3.58, *SD* = 0.80). However, deviation from the mean was large for every item ranging from 0.94 to 1.18. This indicates that the variance of teachers' scores on the self-efficacy scale was large, where some scored very high and others very low.

The study also found that all the three variables, use of technology: for instruction, for lesson preparation, and administrative activities were significantly related to mathematics teachers' self-efficacy in technology integration. This may suggest that either the use affected mathematics teachers' self-efficacy or self-efficacy affected mathematics teachers' use of technology. When the effect sizes were calculated, a large effect size of 12% was seen to explain the difference in the first hypotheses, and a moderate effect size of 6.8% was used to explain the difference in the second hypothesis. However, in the third hypothesis, there was a low effect size of only 4.6%. The relationship between technology use and technology integration self-efficacy has also been discussed in various studies. Li, Garza, Keicher, and Popov (2018) reported that teachers' self-efficacy was a significant predictor of their use of technology in education. Using the TAM model, Joo, Park, and Lim (2018) found out that teachers' intentions to use technology were influenced by their levels of self-efficacy. This may suggest that mathematics teachers with high self-efficacy in technology integration are more likely to use technology in their teaching practices.

LIMITATION OF THE STUDY

This study employed survey design to obtain information from mathematics teachers in selected schools from Dar es Salaam. Also, the study collected background information such as experience in years as categorical data. This limited the range of statistical analysis techniques that would be used for the data especially in explaining how it relates to technology integration self-efficacy. Future studies may explore such variables using a scale so as to obtain continuous data for more statistical analyses. Furthermore, the nature of the data being quantitative limited the analysis to statistical interpretation. Future studies may seek to understand in detail the subject by collecting qualitative information.

CONCLUSION

The study was designed to examine the association between technology use and technology integration self-efficacy for mathematics teachers. The study found a link between the use and self-efficacy with regard to technology integration. The overall self-efficacy in technology integration was seen to be moderate. Also, whereas many (68.8%) teachers were found to use technology for lesson preparations, very few (11.2%) of them reported to use technology for instructional purposes. It may be concluded that efforts are needed to develop teachers' self-efficacy in technology integration and facilitate their actual classroom technology integration.

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epiSTEME 8

Mokashi et al.
pp. 290-298

REFLECTIONS FROM HANDS-ON SCIENCE WORKSHOPS FOR TEACHERS: 'LISTENING' TO TEACHERS

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We share experiences of teaching-learning from hands-on science sessions for school teachers on the topic of Heat and Temperature. We reflect on these experiences to look at issues regarding the learning of science that emerge, to critique our approach and to think about making changes in our approach and revisiting goals of the workshop sessions. We also refer to the works of Eleanor Duckworth to contextualise these reflections.

> So what is the role of teaching, if knowledge must be constructed by each individual? In my view, there are two aspects to teaching. The first is to put students into contact with phenomena related to the area to be studied—the real thing, not books or lectures about it—and to help them notice what is interesting; to engage them so they will continue to think and wonder about it. The second is to have the students try to explain the sense they are making, and, instead of explaining things to students, to try to understand their sense. (Duckworth, 1996 p. 173-174)

TEACHER WORKSHOPS ON HANDS-ON SCIENCE

We have been part of an intervention to encourage hands-on science in government schools for children from indigenous communities of Maharashtra. The programme aims to create opportunities for students to perform experiments in small groups and to promote classroom practices that give space for student-talk and conversation. Workshops for teachers on hands-on science are an important component of this programme. In these workshops, which are guided by facilitators (which included us among others), teachers are expected to do short science experiments or activities in groups, discuss their observations and the causes for the same within the group, and articulate these in front of everyone. This is for teachers to experience different pedagogical approaches which they could adopt and adapt for their respective classrooms. However, given the limited time that each team of facilitators gets with any given set of teachers due to constraints of logistics and expenses, there are unsaid demands to attain certain pre-decided learning outcomes related to the textbook content at the end of every session. These demands are also due to the fact that there is enormous pressure on teachers to make students 'learn' answers to textbook questions so as to pass written exams. Due to this, many teachers tend to not see the need to do experiments or to make students perform experiments and talk about them. So, in a sense, the onus is on the facilitators to convince teachers about the need to consider an approach different from their own.

A substantial proportion of teachers come to the workshops expecting to be lectured at, and they take some time to get used to discussing in groups and speaking about their interpretations and observations. There have been several instances of teachers running out of patience and demanding to be just told “the answer” rather than having things to emerge from the discussions. Teachers have also expressed their problems – in terms of the difficulties in having students discuss within the classroom, them having to ultimately teach to the test, students’ problems in reading and writing due to lack of familiarity with Marathi - the language of instruction, the logistics of arranging and maintaining setups for multiple groups of students, especially given systemic problems such as shortage of teachers and laboratory assistants, and the varied kinds of administrative load on teachers who are often treated as the lowest rung of the bureaucratic ladder. These are all of course connected to broader issues of government policy, assessment criteria, the recognition within the public education system of the importance of the work that teachers do, and teachers’ sense of identity, autonomy and pedagogic practice (Unterhalter, McCowan, & Rampal, 2015). The workshop sessions cannot be seen as happening in a vacuum or in any way separate from this larger context.

WORKSHOP SESSIONS ON HEAT AND TEMPERATURE

In this paper, we will share our experiences from sessions on the topic of ‘Heat and Temperature’ conducted with teachers over two different workshops. In the first workshop, held in July 2018, there were 5 groups of teachers and in the second workshop, held in November 2018, there were 2 groups of teachers, with each group comprising about 30 teachers. A single session in a workshop was of 1 and ½ hours duration and we got two such sessions with each group of teachers in each workshop. The plan for the three hours was to discuss key topics in heat and temperature from middle school science with the teachers. In each workshop, sessions on various topics ran in parallel, with different batches of teachers attending these sessions in a staggered manner. The teachers who participated in the workshop were middle and high school teachers with varying background in science, with some having studied science only till class 10 and 12 and some being science graduates and very few post graduates in science.

Most of the experiments and activities conducted with teachers were modifications of those found in text-books on hands-on science that have emerged from similar work done in the past. The session plans were partly driven by the textbook contents and were partly emergent in nature. Our team would discuss how things fared and also share these details with the larger group of facilitators at the end of the day for feedback and suggestions that could help modify the next day’s sessions. We discuss here some episodes of teachers’ engagement in experiments and discussions in smaller groups as well as in whole group. We particularly focus on the details of teachers’ ideas and articulations about certain concepts from this topic, both as examples for drawing pedagogic ideas from, and for the specific ways in which people understand these concepts. We believe that learning from these experiences with teachers might help inform the workshop and session design for future work.

An experiment on the thermal expansion of air

Among various experiments on modes of heat transfer and expansion in the three phases of matter, teachers performed an experiment to observe the expansion of air. A small ‘injection-bottle’ made of glass was used for this experiment. (This is a demonstration developed by Umesh Chauhan, a retired teacher who was part of the Hoshangabad Science Teaching Programme) A hole was made in its rubber cap and an empty ball-pen refill was inserted. A drop of coloured water was put in the refill. Upon holding the bottle in one's palm, the drop moves up the refill away from the bottle. The experiment was first demonstrated to the teachers and then they were asked to perform it within their smaller groups with each group given separate apparatus. Then, a question was posed to the teachers- "What do you observe and why do you think it happened?" - which they were supposed to discuss within their group of five people for about 15 to 20 minutes and then each group's discussion was to be shared with peer-groups.

One teacher tried to build a microscopic picture of expansion - "*When we see air expanding upon heating, what's actually happening is that the molecules of air themselves expand*". This picture seems to attempt to accommodate the macroscopic expansion of the air in the bottle that can be sensed/seen with the 'atomic-dogma', namely that 'all matter is composed of atoms'. This corresponds to the 'continuity' assumption (Talanquer, 2006 p. 813) "that matter can be continuously divided into smaller pieces. These pieces or particles of matter have the same qualitative properties as the macroscopic object... they expand and lose weight when heated", as well as with the heuristic of 'similarity' used for reasoning about causal relationships: 'If the properties and behavior of atoms and molecules are the cause of the observed macroscopic phenomena, these invisible particles should share the features of the things we can observe (color, density, motion)' (Talanquer, 2006 p. 814).

It is interesting that this microscopic understanding of matter, shared by the teacher, is common among students (Talanquer, 2006). Maybe there are many more 'naive' ideas or theories, which are common among teachers as well as students. 'Listening' to teachers could bring forth such ideas, that could be taken up for further discussion, experiments and thought.

On the expansion of air, another teacher wondered - "*Will the air keep expanding forever if we keep on giving heat?*" We think that this was a leap of imagination that tried to extrapolate much beyond the immediate situation that we were looking at. We are of the opinion that wondering about asymptotic/limiting behaviour of phenomena is a sign of deep thought and reflection. We were aware that the thermal expansion coefficient of an ideal gas is inversely proportional to the temperature, but none of us (facilitators) had ever considered this perspective. We feel that taking this particular path into the relation between the flow of heat and the resulting expansion might suggest engaging and meaningful investigations and ideas.

Another teacher thinking about the mechanism of heat transfer said, "*I wonder how the heat goes from my palm to the air inside the bottle - is it by conduction or by convection*", and then offered an answer after a while - "*Heat goes into the bottle from the palm by conduction as the bottle is at a lower temperature than our hand. The air comes in contact with the bottle and heats up.*" The latter phenomenon, namely of heat flowing from the bottle to the air within, is a non-standard scenario for convection. The textbook-demonstration of convection (that the teachers had performed before this experiment), involved a heat source at the bottom of a beaker that sets up convection currents in water, while in this case, the heat source (the palm) is all along the horizontal walls of the bottle; thus the pattern of the convection currents will be complex.

The teacher was attempting to use his understanding of different modes of heat transfer to make sense of a more complex scenario. We could have undertaken an investigation into these details with teachers as an example of the nature of scientific phenomena, that they do not come in a neat compartmentalised form.

In one of the sessions during the second workshop, which was held during the winter, it was observed that the air inside the bottle was not expanding immediately after holding the bottle in one’s palm. A teacher got up without speaking to keep her group’s bottle in the sunlight by the window and all of us witnessed the subsequent expansion of the air within. This was a spontaneous decision taken by the teacher to use a source of heat that was readily available. It might have been worthwhile to talk about the teacher’s experiment and how it was different from what facilitators had planned, to compare and contrast the processes in the two cases. One of the facilitators kept the bottle back in the shade and the drop came down slowly. A few people wondered in passing why it takes more time to cool down and contract as compared to the expansion on heating. Perhaps this could have been a chance to discuss and investigate the nuances of heating by radiation, comparing the rates of heat transfer by conduction and radiation and questions like - does the air heat up directly by sunlight or does the bottle heats up by radiation and then transfers the heat to the air within, or a combination of these two.

In a different session, one of us overheard a conversation between two teachers: “*Don’t press the bottle too hard, it might break*”. “*No, no. If I hold it tight, the contact will be better*”. This remark seems to be grounded in some everyday experience about thermal contact (such as applying a warm compress or even an ice pack), and discussing about this could have helped unravel the details of the mechanisms of heat flow, such as the dependence on the area of contact in this case. We feel that we might have missed several such ideas expressed within groups, ideas that people did not deem worthy of expressing in front of everyone.

While trying to explain the reason for the upward motion of the drop when the bottle is held in the palm, one of the teachers came up with an explanation: “*Hot air is lighter, so it rises and pushes the drop up*”. Our colleague, Umesh Chauhan, showed a counter-experiment to the teacher - to hold the bottle upside down and to see that the drop goes down after a while, moving away from the bottle. This was supposed to be evidence to claim that all the air inside the bottle expands, however we couldn’t spare time for a discussion on this experiment (So we are not sure how the teachers interpreted it). Some teachers also placed the bottle horizontally and repeated the experiment, which was an attempt to eliminate the effect of gravity, and saw that the drop still moves outwards. This was an instance of teachers extending an experiment to try to separate the effect of gravity from thermal expansion and it was noticed by one of us. However, we missed the opportunity to bring this to the notice of the entire class, which might have led to a more detailed understanding and discourse about the phenomenon. It is possible that teachers in other groups too might have tried their own modifications of the setup to test out their reasoning, but they perhaps did not deem it important enough to share with others (or our approach gave the impression that their ideas do not matter).

As an extension to this experiment, we did another one to observe contraction on cooling. We asked the teachers to repeat the experiment and then to dip the bottle (which now has air at a temperature slightly higher than room temperature) in a mug containing water (from a bucket that had ’normal’ water that had been in the room since it was filled from the tap in the morning). All of the groups noticed that the coloured drop in the refill moves in the opposite direction indicating that the air which had been heated by our palms contracts after being cooled. A teacher observed that the coloured drop in the refill moves to a position distinctly lower than its original position from where it started in the experiment on heating by holding the bottle. Someone remarked that this means that the ‘normal’ water which had been in the room since morning wasn’t at room temperature. This turned out to be a minor revelation, as most of us shared the notion that all objects in a “room” are at room temperature. This discussion could have led to investigating the reasons for the same, or to think about the heating and cooling of different objects over 24 hours, and the mechanisms involved.

Thought experiments on mixing water

Our colleague, Kamal Mahendroo posed thought-experiments to the teachers that involved mixing water. These were modifications/extensions of those cited in literature (Driver, Guesne, & Tiberghien,1985, p. 62) and were about the relation and the difference between heat and temperature.

One of these thought experiments went as: ‘We have two containers each having one litre of water at 20 degrees Celsius. What will be the final temperature and total heat content of the mixture if we mix the two?’

Most of the teachers said that the temperature will remain the same. Some teachers pointed out with conviction that their students will say that the final temperature will be 40 degrees, as they typically tend to add up numbers in any word problem. The work of Stavy and Berkovitz (1980) on this particular result has revealed details of how students try to reconcile their ‘qualitative-intuitive/verbal’ and ‘quantitative-numerical’ understanding of this phenomenon.

The teachers suggested three ways to make students see the problem in this answer- 1) to actually make students touch the water and feel for themselves if the water feels hotter after mixing, 2) use a thermometer and 3) give them a counter-example: If we mix hot water and cold water we get lukewarm water, say for having a bath. It’s not like we get warm water by mixing two containers of cold water. (Stavy and Berkovitz (1980) discuss the finer details about the effectiveness of the use of cognitive conflict in this and related scenarios).

Thus, teachers were expressing not just their own beliefs, but they were also reflecting about how their students might think around these questions and what kind of replies students might provide. So their engagement with the concepts was at multiple levels.

For the second part of the question on thought experiment, ‘what will be the total heat content of the water after mixing’, we asked teachers to compare the heat content of the mixture with X (where X is the heat content of the one litre water at 20 degrees in one container) - whether it will be less than, greater than or equal to X. The teachers seemed unanimous that the heat content of the two litres of water after mixing will be equal to X - at least the majority of people supported this view, with a few unsure people who chose not to speak up. Upon being asked to explain their answer, a few teachers said that just like the case of temperature, heat too will not add up and will remain the same - i.e. the heat content of two litres of water is the same as that of one litre of water at the same temperature.

We resorted to an indirect example to problematize this conclusion by presenting them with the following situation- Suppose that every day you heat ten litres of water (that is at room temperature) on a kitchen gas-burner to make it hot enough for your bath. One day, you have a guest and you have to heat twenty litres for bathing using the same kitchen gas-burner. We posed the questions- Which of the two would take more time to heat? So, in which of the two cases did you supply more heat? Several teachers remarked that the ten litres as well as the twenty litres were both at about the same final temperature, but we had supplied more heat to the latter. The second one was a kind of a leading question, to hurry up reaching the destination we wanted the teachers to reach. We feel that although this helped us in meeting our session goals, there was insufficient time given to teachers to reflect on and express their ideas about heat and how it is different from temperature. In that context, we do not know if teachers were able to make sense of the idea of heat as energy.

At this point, most people started questioning their previous conclusion about the heat content in the thought experiment. Amidst the now seemingly unanimous opinion of the class that the heat content of the two litres of water will be greater than X (with some people saying that it should be 2X), a teacher who had not participated in the discussion thus far, pointed out that generally when we speak of heat we are talking about either supplying heat to an object or taking it away from it. That we rarely talk about the heat content of an object per se. We acknowledged that this was a perceptive comment about the nuances of how the middle-school science textbook treats the concept of heat. It is treated quantitatively while discussing heat being supplied and being taken away (in the formula that involves the specific heat capacity and the change in temperature), while the description is qualitative while talking about heat as a concept by itself ('the total kinetic energy of all the molecules'). Coming at the end of the session, we were not able to engage in this discussion further, beyond mentioning the idea of the Absolute Zero of temperature and considering the total heat supplied to some matter to raise its temperature from absolute zero to a certain value, say room temperature, with the possibility of phase transitions happening along the way.

In the other workshop with a different set of teachers, we presented a thought experiment which was a variant of the one described above. It went as follows- 'We have two containers each having a litre of water, one at 20 degrees and the other at 40 degrees. We can suppose that the heat content of the water in the two containers is X and Y respectively, in some units. If we mix the two, what will be the temperature and the heat content of the mixture?'

All the teacher groups said that the temperature will be 30 degrees, with some teachers saying that it may not be exactly 30 degrees but slightly lower (they felt that some heat will be lost in mixing). Most people seemed convinced that the heat content 'Y' of the water in the second container is greater than the heat content 'X' of the water in the first container as the temperature of the second container is higher. However there were no clear responses about the heat content of the mixture. We put forward three cases and asked the teachers which one is true- the heat content of the 2 litres of water (after mixing) is less than X, between X and Y, or greater than Y. Here too, the reasoning went along similar lines as the other thought experiment and people chose "between X and Y", saying that it should be the same as in the case for temperature. We asked them that if things are the same for both heat and temperature, what is the difference between the two or rather what is the need for these two separate terms. There was a range of responses, from textbook definitions to stating the facts like the units are different, to locating a difference in temperature and heat in terms of cause and effect with conflicts about which of the two being the cause and which the effect. After this discussion, to resolve things, our colleague posed another thought experiment - 'A container has one litre of water at 20 degrees and another container has a thousand litres of water at the same temperature. What is the heat content of the water in each container?' to which the teachers answered that it is the same, say X calories in both.

At this point, we asked the teachers to consider the following scenario- 'Suppose we take out a litre of water from the thousand litres. If the heat content of both was X, will the heat content of the 999 litres that is left be zero? If not, then can we keep on extracting a litre of water and creating X calories of heat?' This example seemed to create dissonance and one teacher mentioned "*Heat is a form of energy*", which we wrote down on the whiteboard. Following this, there were numerous attempts by the teachers to reformulate the idea of heat content in the light of it being a form of energy. We found it an appropriate moment to write down the description from the textbook:

> *What is the difference between heat and temperature? We know that a substance is made of atoms. The atoms in a substance are always in motion. The total kinetic energy of the atoms in a substance is a measure of the heat contained in that substance, while the temperature of a substance is related to the average kinetic energy of atoms.*

At this point, a teacher came up with a narrative to explain this difference to children:

> *Suppose that in a class of 10 children, each child has 20 chocolates, so there are 200 chocolates in all. In another class of 10 children, each child has 40 chocolates, so this class has 400 total chocolates. Now we make the children from the two classes sit together and ask them to keep all their chocolates on the table, after which we divide the chocolates equally among the 20 children. The total number of chocolates (600) signifies the heat content and the number of chocolates per child (30), the temperature.*

When we shared this with some of our colleagues, one of them was dismissive about the teacher's use of the analogy of chocolates as he felt that it creates an incorrect/incomplete picture of temperature as well as misconceptions about heat and temperature, and their units. While there is truth in this, we feel that this particular attempt by the teacher to understand and to spontaneously create an analogy that is appropriate to explain to his students, is an example of a 'wonderful idea' (à la Duckworth, 1996) and a sign of reflection and deep engagement. We feel that this metaphor of chocolates per child brings out the idea of temperature being "*the intensity of heat*" (as put by a teacher), or as their textbook calls it - "related to the average kinetic energy of atoms". However, it is far from clear what sense students and teachers make of "the kinetic energy of atoms" or its average. We believe that it would need more engagement and deliberation to build conceptual understanding of this idea.

LISTENING TO TEACHERS EXPLAIN

The excerpt from Duckworth’s essay at the beginning of this paper mentions giving learners the opportunity to directly interact with phenomena, and then allowing them to explain how they understand things, as two central aspects of teaching practice. We realise that while we did not set out to meet these criteria very explicitly in our work, they seem very much relevant for the way we design or plan sessions. In the context of the rich ideas of teachers that we encountered, we feel that we were not able to give them justice in terms of time to listen to and engage with them and to give them opportunities to explain their sense-making in detail. These realisations by us (as facilitators), which were somewhat obscure, became more apparent in the course of reflecting and writing this paper, and reading around these issues.

While advocating for allowing learners to explain, Duckworth speaks about the results of the way of teaching-learning (Duckworth, 1996 p. 182-183):

> *First, in trying to make their thoughts clear for other people, students achieve greater clarity for themselves. Much of the learning is in the explaining. Second, the students themselves determine what it is they want to understand. It is not only the explanations that come from them, but also the questions. Third, people come to depend on themselves: They are the judges of what they know and believe.. Fourth, students recognize the powerful experience of having their ideas taken seriously, rather than simply screened for correspondence to what the teacher wanted.. Fifth, students learn an enormous amount from each other.. Finally, learners come to recognize knowledge as a human construction, since they have constructed their own knowledge and they know that they have. What is written in a book is viewed as somebody else’s creation, a creation produced just as they produced their own. Its origin is not of another order.*

Further discussions and investigations into phenomena originating from the thoughts and ideas expressed by teachers in the sessions have the potential to realise the results given in the above extract. The final point is in turn related to the nature of science as not merely a body of knowledge but also a process of human inquiry which is a work in progress, not knowledge handed down by authority figures but that constructed by people through their deep engagement with physical and social phenomena (Rose, 2006, p. 143; Singh, Shaikh & Haydock, 2019). Teachers who did not feel comfortable speaking in public had the chance to discuss with their group members, and we saw glimpses of this explaining and learning from each other in the sessions. However, our insistence on moving on and not pausing to listen to teachers’ ideas fully, perhaps gave the message that their ideas are not important or we might be reinforcing beliefs such as the ultimate authority of the textbook, of experts. **Unless we ‘listen’ to teachers, unless teachers realise that their ideas are important and relevant, we as educators cannot meaningfully engage with them.** We feel that if we are able to create conditions for teachers to take their own and others’ ideas seriously in these sessions, perhaps they might start doing the same with their own students at school. Unless teachers themselves get a chance to engage in and appreciate a process of inquiry, they would not be able to help their students experience it. This would mean that we set aside substantial time in session-plans for teachers to explain their ideas, to work on them further, and “to slow down closure, in the interests of breadth and depth” (Duckworth, 1996 p. 76).

It is important for teacher-educators and for teachers to realise that workshop sessions are not going to 'make the concepts clear' or 'cover the topics'. We need to recognise both knowledge construction and improving teaching-learning practice as continuous on-going processes. This calls for giving teachers more autonomy and responsibility as workshop participants, besides moving towards beliefs about knowledge construction that are more in line with the way people learn. Also, teachers need consistent support and time to reflect and to keep working on these processes (Rodgers, 2001).

Using textbooks, blackboard teaching or say, reading about the historical development of scientific concepts are important parts of learning. However, "..putting ideas in relation to each other.." (Duckworth, 1996, p. 81) and "..(to) come to understand subject matter inside out.., becoming aware of the web of connections within it, and the connections between one area of content and another" (Rodgers, 2001, p. 479) is work that needs to be done with patience and joy. We believe that fixing systemic issues such as assessment criteria, teacher and student autonomy, government policies on public education, equity in access to quality education (NCERT, 2005), is a battle that will have to be fought in parallel with assisting teachers to work on their practice autonomously, collegially and collaboratively.

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CONSCIOUS TEACHER TRAINING: SUPPORTING INNER DEVELOPMENT ALONG WITH DEVELOPING SKILLS AND COMPETENCIES

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The purpose of education is beyond fitting in (getting a job, being a good citizen) and standing out (having a successful career, being a critical thinker) it should allow children to simultaneously know themselves and embody values, notice patterns they want to shift in society and solve problems. What would be the qualities of the teacher, facilitator who can guide the students to be such leaders?

How can a technical teacher training program, in this case study, a course on the use of programming to learn Mathematics for teachers (educators), be designed to support these qualities in teachers? When such a design is implemented does it achieve its purpose of addressing not just skills (programming, solve problems), but competencies (how to use skills to change culture or shift systems), and inner capacities (working from embodying values)?

CONTEXT AND INTRODUCTION

Auroville is a universal township with a goal of realizing true human unity. Auroville belongs to humanity as a whole and works on physical and spiritual researchers required to achieve its goal.

STEM (Science Technology Engineering Mathematics) land – runs rural STEM centres in two outreach schools of Auroville – Udavi School and Isai Ambalam School. The children attending both Udavi and Isai Ambalam schools come from villages surrounding Auroville. The schools of Auroville and STEM land work on the philosophy of Integral Education based on the principles of Sri Aurobindo and the Mother.

Integral Education looks at holistic development of a child; developing and perfecting the physical, mental, vital (psychological, emotional) natures of a child to allow them to express their inner being in the world (Neeltje, 2001). This will not only benefit themselves (independent/individualistic), but also the world (interdependent/collective). Such an education addresses the purpose of education beyond fitting in and standing out.

The environment most suited for Integral Education is one where the child progressively learns about himself/

herself and can make choices on their own. This environment is broadly referred to as '**Free Progress**' system, where children are provided freedom make progress towards learning and understanding themselves deeply. At a practical level this appears as freedom with responsibility in learning. While the responsibility of learning rests with the child, it is the teacher/facilitator who has a big role in creating a meaningful learning environment and this role is far larger than that of a traditional didactic teacher. How this philosophy can be implemented is one of the challenges and the research carried out at Auroville Schools.

At STEM land in Udavi school children learn Mathematics, Electronics, 3D Printing, Programming (in Scratch, Alice, Geogebra), Mindstorms (Robotics) and play strategic games that enhance logical thinking. The children take responsibility of their learning (Ranganathan, et.al., 2017) and plan their goals each week related to their curriculum and beyond it. This self-directed learning is based on Sri Aurobindo's first True principle of education (Aurobindo, 1921); "*Nothing can be taught*". The children create projects that represent their mastery over concepts they learn and can share following constructionism (Papert, 1986). They work individually, in pairs or peer groups and ask for support from facilitators when they need it. At STEM land at Isai Ambalam school we work with younger children work on tangible real-life projects that impact their surroundings and school addressing Mathematics and EVS (Iyyanarappan, et.al., 2019).

Scaling: How can such a program be scaled to different contexts; different levels of skills of facilitators and varying availability of resources was one of the questions that drove this research. We felt that scaling what was special about STEM land was not the access to materials, or skilled staff, but the environment of taking responsibility of one's learning. Creating an environment where children can use freedom responsibly was not easy and required teachers or facilitators to have the courage to step beyond their socializations and create an environment that worked for the children and themselves. The goal was to avoid prescriptive top-down (or bottom up approach) to one that was inside-out with the teachers manifest what they care about deeply in their workspaces while being equipped with STEM skills.

This is an action research, the paper reflects on the design and implementation of a teacher training program that builds capacity through skills, competencies and inner capacities.

PRINCIPLES UNDERLINING THIS WORK

The focus of the paper is teachers/facilitators and their training. In this regard the principles of true education by Sri Aurobindo (Aurobindo, 1921). indicates that '*The teacher is not an instructor or taskmaster, he/she is a helper and a guide. His/Her business is to suggest and not to impose.*'

The NCF 2005 (Pal, et al., 2005) also states '*teacher plays a role of a facilitator, supports and encourages learning, involves active participation of learners, develops multidisciplinary curriculum, focuses on education, brings about multiple and divergent exposure, multifarious, continuous appraisal in educational system'* these are very high goals for which teacher's initiative and leadership is important.

Making projects (through programming) is a way for children to demonstrate their learning and offers an alternative to examinations for assessment. Projects also offers an opportunity for self-evaluation and constant progress. Programming a computer helps children learn conceptual ideas as they need to break it down into small bites for a computer to follow. It also helps them visualize abstract concepts. They can also create their own games to develop rigor. Work on programming and learning Mathematics that has been carried out at STEM land and documented before and not repeated here (Ranganathan, et.al, 2015) is the basis of this course.

This 8-day program designed in line with capacity development to address sustainable and holistic results through a conscious full spectrum response (CFSR) (Monica, 2017, p. 236) as shown in Figure 1. A CSFR based capacity development simultaneously addresses.

1. immediate causes that requires technical solutions through skills
2. systems and cultural causes that require system and cultural transformation through competencies
3. underlying factors that require embodying values and being a transformational leader through inner capacities.

The figure also conveys the definitions of skills, competencies and inner capacities.

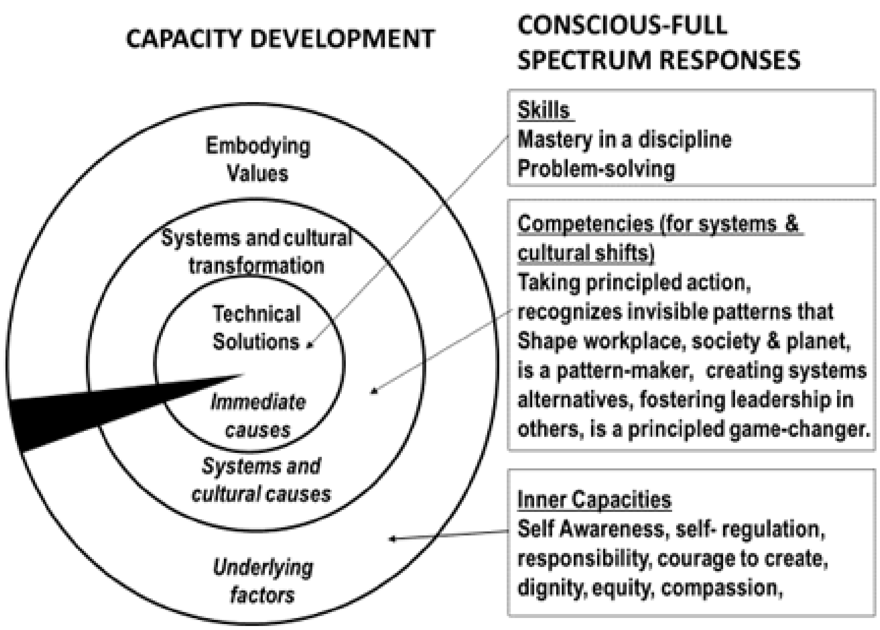

Figure 1: Capacity Development for sustainable results at scale.

DESIGN OF TEACHER TRAINING PROGRAM

In line with the principles above the target outcomes of this training program was:

Skills

Creation of projects through programming was one of the core skill areas of the program where teachers themselves learned creating projects to addressing challenges.

Basic & Intermediate (for Mastery)
- Scratch Programming – Interactive queries (sensing), drawing different shapes (pen), animated stories (events, looks), maze game, blocks or functions in scratch, concentric circles with perimeters(variables), and mathematical concepts, pen (shapes, mandalas), fractions, coordinate geometry, graphs.
- Geogebra: Introduction, drawing shapes, midpoint, ratio of perimeter of circle to different polygons that fit in a circle.
- Using hardware for programming : Makey-Makey.

Expert (for exposure and for those who were already at intermediate level before the course)
- Scratch Programming - number line (integers subtraction), algebraic identities, square and cube roots (of large numbers), vernier callipers (explanation), nuclear fission (animation).
- Using hardware with Programming - Scratch: Finch robots, mindstorms, interactive camera, Snap for Arduino.
- Geogebra : Solar system, mandala, clock, interactive inputs, animation.
- Programming with Alice 3D - Introduction to a 3-D world, setting up a scene and props, customizing characters and animation.

Competencies
- Ability to listen deeply, reducing judgements and biases.
- To notice my own socialisation and not be limited by it.
- Recognize the invisible, multiple patterns and systems that shape societal and planetary situations and actions; recognize interdependence.
- Design and deliver on actions through CFSR, simultaneously in real time (1) source wisdom (2) shift systems and (3) solve problems.
- Enrolling partners through responsible speaking.
- Looking for commitment for action behind complaints.

Inner Capacity
- *Self-awareness*: What I stand for and my socialized fears. Courage is not the absence of fear, but my ability to transcend my socialized fears and act from my stand.
- *Self-regulation:*
    - o Distinguish one's wisdom (stand) from social, professional and personality identities (or profiles). Embrace all with respect for diversity (using wisdom profile).
    - o Noticing my Background conversation (based on socializations) and still myself for listening deeply to a person (or a child).
- *Courage to create:* Creative solutions with CFSR.
- *Responsibility*: Integrity lens noticing my wholess in being my word, looking for alignment in my work and my values - speak up and speak out, being the change, I wish to see - *embodying values*.

The participants of the training program were from Auroville, Pondicherry, Chennai, Gujarat, Mumbai and

Sittlingi. Most worked with NGOs working with marginalized communities including slum children, tribal children and rural children studying in government schools. The background of the participants was also diverse from teachers working on supplemental computer sessions to school management. One of the goals was to train people from around Auroville to allow them to start STEM centres in their own organizations. Each day of the workshop addressed each of the areas of skills, competencies and inner capacities and the plan for a typical day is shown below:

Day 2 - 03/05/19	
9.30 - 9.50	Sharing insight (what I learned about myself yesterday)
9.50 - 11.00	Noticing my Background conversation (based on socializations) and still myself for listening deeply to a person (or a child)
11.00 - 11.10	Thought Break – Walk, stop, clap, name
11.10 - 12.30	Scratch Programming continued: Drawing Shapes or Mandalas or Pythagoras theorem (depending on their plan)
12.30 - 1.30	Lunch
1.30 to 1.40	Inspirational videos: Isai Ambalam Video (10 min)
1.40 - 2.45	Scratch Programming continued: Projects on fractions/pie chart.
2.45 - 3.00	Break
3.00 - 4.25	Advanced Scratch Programming: Mindstorm using Scratch 3
4.25 - 4.30	Daily Reflection + Quotation of the day
Take home activity	1. Draw a mandala or any shapes using pen in Scratch 3 2. Using variables and random number show multiplication

Table 1

METHODOLOGY OF THE RESEARCH

The data for the research collected from the software program created for the course to track the progress of the participants. The software captured:

a) Survey data collected from feedback for the course at the end of the workshop. In the survey the participants conveyed what they felt they learned through the course under skills, competencies and inner capacities.
b) Daily learning and self-evaluation entered by participants that was used to record the learning each day as well as a repository of projects made by them to verify skills learned.
c) Insights shared in plenary each day as unlike skills, competencies and inner capacities expressed by participants are subjective and harder to verify. However, insights gave a sense of these and some are reported here.
d) Few notes based on communication/interaction with participants on what they have implemented after the workshop.

RESULTS

Skills

The survey on the skills (Fig 2) indicate that most participants felt that they had mastered many of the basic and intermediate programming outcomes.

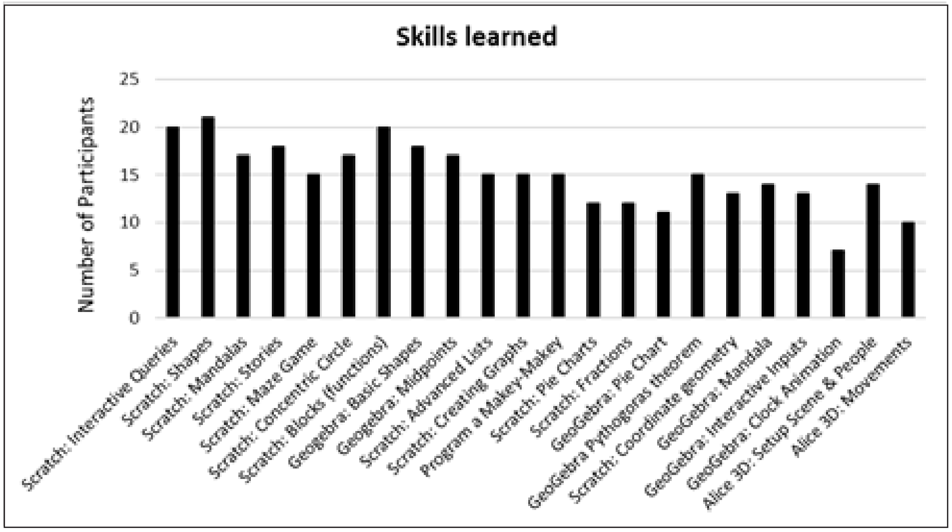

Figure 2: Skills vs the number of participants who felt they acquired them.

We stored all the projects made by participants and we saw that most had completed the challenges and made projects (outputs) requiring these skills. Within the 8 days 10 participants completed over 16 projects. The survey then reflects the confidence of the teachers in these skills (outcome). Many expressed their awareness of the expert topics we included for exposure. A few even took on the challenges of the expert skills and demonstrated these through their projects.

Competency

The survey results on the competency (Fig 3) indicated that they learned tools that would make them more effective to work with peers and management. They also started looking at solving problems in more than one way, listen deeply to others, being able to notice commitment for action behind complaints, give feedback and speak powerfully from values to enrol others. Many participants designed their CFSR directed at what they would do differently with the skills they acquired at the workshop to and shape learning back home. They also shared these projects linking their values and cultural shifts they hope to bring through them.

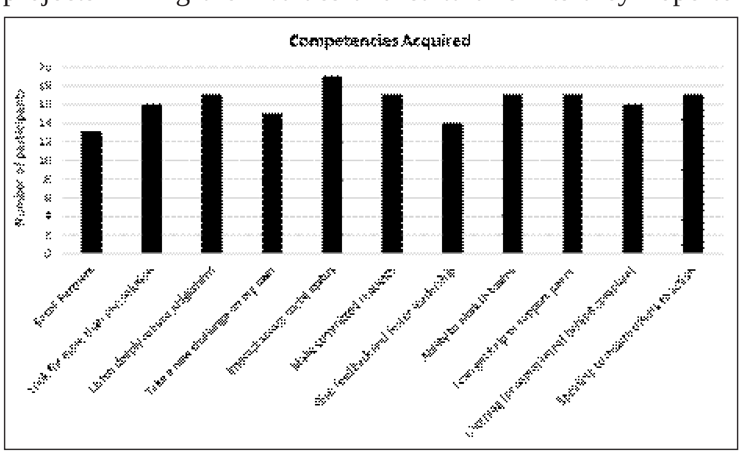

Figure 3: Competencies and number of participants who felt they had acquired them

Inner Capacities

The survey indicates on inner capacities (Figure 4) indicates that all participants became more self-aware and went beyond their socialized fears even in the duration of the course. Many initially found some of the aspects of the course hard and were able to persevere and learn it. Similarly, many were uncomfortable stepping in front of an audience and sharing their insights or projects at the beginning of the course but came forward to do so at the end of the course.

They were also able to notice their socializations especially cultural and how this impacts their perspectives. We noticed that with each exercise participants became more comfortable breaking their social and professional barriers for example teachers working with educators (school management).

Many of them noticed systems and cultures. They and were able to design beyond technical solutions using a CFSR that included system dimensions in their organizations or classrooms. They spoke in front of an audience and shared their designed breakthrough initiatives designed. They demonstrated the courage to create and seven of the participants who were not involved with programming before the workshop started using programming with children and/or set up STEM centres. Since the course **four new STEM** centres were started by the participants at Aikiyam school, Thamarai, Auroville Institute of Applied Technology and Auroville schools.

They took up responsibility and noticed when they were in and out of integrity.

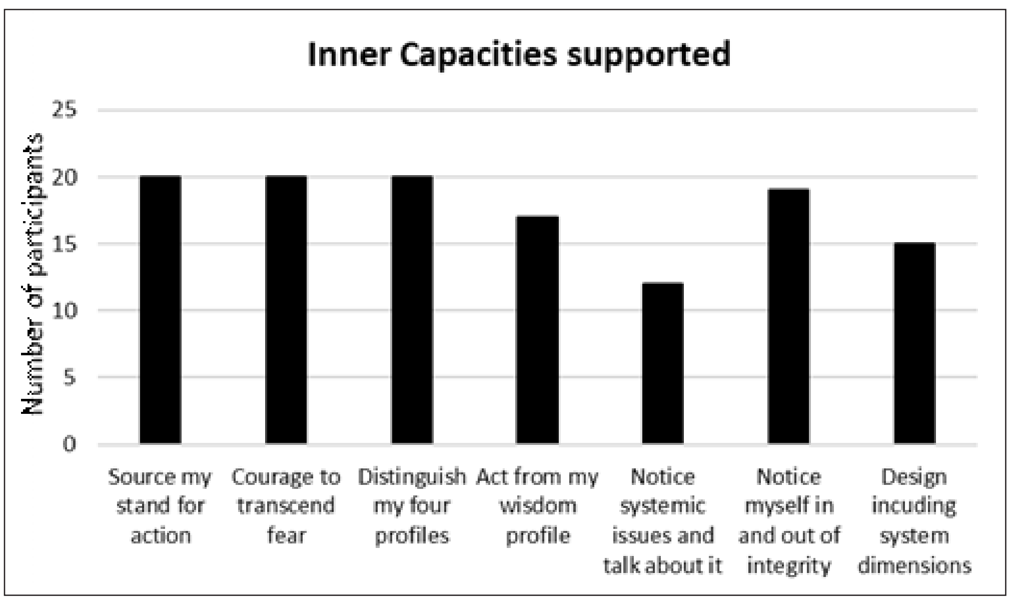

Figure 4: Inner capacities and the number of participants who believed they were able to exhibit it through the workshop

Some insights from participants

Unlike skills, competencies and inner capacities are harder to measure directly and we share some of the insights of participants to aid this:

'I will encourage myself and the children I work with to experiment freely and try new ideas without fear of failure.'

'If I think I know something and other person is conveying the same to me I won't even listen to them, but I now realized that when I listen deeply, I was able to learn new things which I did not know before.'

'I noticed that I am able to move beyond win-lose to win-learn' [Move beyond fear of failure]

'I learnt my four profiles (wisdom, social, professional, personality), especially social profile that I am more attached to and make me think deeply about it.' [I need to work beyond my social profile]

'I noticed that I expect society to be based on how I grew up.' [My current socializations]

'I learned to be authentic and not to try to impress people.'

'I was able to look at the problem differently and get a structure for the ideas on how to go about solving it.' [Conscious Full Spectrum Response vs a partial response]

'I realized that I do not need to stop when I get one answer and keep looking for more.' [look at many ways to solve a problem to support children's learning]

CONCLUSIONS

To support future leaders in children the teachers of today themselves need to be equipped with leadership capacity. A technical training program on programming for learning Mathematics was designed in line with capacity development to create sustainable and holistic results through a conscious full spectrum response (CFSR). A CSFR based capacity development simultaneously addresses immediate causes, systemic and cultural causes and underlying factors through skills, competencies and inner-capacities.

The skills, competencies and inner capacities targeted in this program were listed and analysed based on surveys at the end of the course, projects that participants created and in their reflections on each day.

We find that many participants felt they had acquired competencies and inner capacities along with skills in the program and this supports development and use of these skills creatively beyond what was already done at STEM land. This supports emergence rather than prescriptive design and implementation necessary for scaling. At the end of the program, the participants have demonstrated their courage to create and **seven** participants who were not involved in STEM earlier have started teaching programming and created four new STEM centres so far.

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MISSED OPPORTUNITIES: INSTANCES FROM GEOMETRY LESSONS

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We present instances from two high school Geometry lessons where the teacher is faced with contingent (Rowland & Zazkis, 2013) situations. We propose a framework to analyse the responses of the teacher in each of these scenarios to understand opportunities taken, built on and opportunities missed. Then, we propose some suggestive activities that could be taken up for these scenarios consistent with the mathematical modes of inquiry. The framework is aimed at providing insights to teachers to reflect on their teaching learning practices and help in their development of professional noticing (Jacobs, Lamb, & Philipp, 2010).

WHY INDIAN CLASSROOMS AND MATHEMATICAL INQUIRY?

Indian classrooms are typically large sized. With an average class strength of around 50 students or more, it becomes often difficult for teachers to address students' diverse responses. However, if the teacher does not pick at least some of these responses to probe their thinking further, such a practice cannot lead to meaningful facilitation. 'Professional noticing of children's mathematical thinking' entails an integrated teaching move that comprises of attending to mathematical strategies in students' responses, interpreting these details against research on children's mathematical development and deciding on how to respond (Jacobs et al., 2010). The discourse on 'missed opportunities' (Rowland & Zazkis, 2013) seeks to attend to the opposite of planning, to situations that are unplanned and require an act of improvisation by the teacher. The contingent situations, generally arising out of students' responses in classrooms, are excluded from the teacher's lesson image (Schoenfeld, 1998). Rowland and Zazkis further argue that contingent situations provide opportunities for educators to demonstrate a commitment towards the modes of inquiry in mathematics. That apart, such situations may also induce anxiety in teachers due to "uncertainty about the sufficiency of one's subject matter knowledge" (Rowland, Huckstep, & Thwaites, 2005, p. 263). Research suggests that a better understanding or experience with foundation, transformation and connection (Rowland et al., 2005) aspects of mathematical knowledge would better dispose teachers to be able to meaningfully deal with such situations and drive mathematical modes of inquiry. Rowland identifies two aspects to responding to contingent situations: readiness to respond to children's ideas and preparedness to deviate from a set out agenda. In this paper, we will examine two contingent classroom situations from the classroom conversations of Grade 9 students from a government-run school in Dhamtari district of Chhattisgarh state in India. The aim of the analysis is to not identify gaps in teaching or teacher knowledge but to trace trajectories of teacher-support for furthering possible explorations in school mathematics lessons.

THEORETICAL ORIENTATION

Previous research has shown that when pursued contingent situations have the potential of providing some interesting and fruitful learning opportunities (Rowland et al., 2005). The capacity to make fruitful use of such situations by teachers is dependent on their knowledge of the mathematical potential in the contingent situation and a commitment to mathematical enquiry, as illustrated through the examples of Laura and Bishop's (Rowland & Zazkis, 2013) stories. Expanding on Rowland's framework for this analysis, we propose following framework to analyse the teacher's responses to contingent situations:

Case 1: Opportunity underestimated or not understood
Case 2: Opportunity understood but ignored due to conscious choice or mathematical potential not recognized
Case 3: Opportunity realised but unable to build on the mathematical potential
Case 4: Opportunity realised and successfully built on the mathematical potential

The analysis follows with a suggestive grade appropriate exploration that educators can take up as follow-up of such contingent situations, which is dependent on teacher's ability to notice such situations and follow up on them through designed experiences. The use of Dynamic Geometry Environments (DGEs) for guided exploratory activities (Zbiek, Heid, & Blume, 2010) have been developed and analysed through the lens of expressive and exploratory nature of such exercises. We have used van Hiele theory of students' geometric reasoning development as the underlying structure for elaborating on the levels and types of these dynamic activities (Manizade & Mason, 2010).

METHODOLOGY

Non-participant classroom observations were done by the researchers as part of the Connected Learning Initiative (CLIx) programme (www.clix.tiss.edu), an ICT based educational intervention run by TISS, Mumbai, being implemented in select secondary schools in four states of India. The study focused on lessons on Geometric Reasoning taught to Grade 9 students. The observers (authors and colleagues) took running notes sitting at the back of the classroom and audio-recorded the classroom proceedings for triangulation. These observations were preceded and followed up by conversations with the teachers about their teaching plans and reflections on teaching. Post observation phase, contingent situations were identified from these notes and analysed as per the framework proposed above.

For the creation of guided exploratory DGE (GeoGebra) based experiences, expressive (Sherman, 2010) activities have been created and a suggestive approach to these mathematical inquiries has been laid down in order to provide concrete strategies for teacher facilitation. GeoGebra, a free DGE has been used for these activities in line with the existence of the ICT infrastructure and facilities available in the concerned school.

CLASSROOM SCENARIOS

From the point of view of researchers, it is always possible to point out to aspects of classroom, instruction, assessment, resource materials and classroom processes that may theoretically not be invoked in their ideal manifestations. Instances like not seeing value in discussing the 'axis of rotation' while talking about rotation of 2D shapes, ignoring a students' response that 'all sides of a parallelogram are parallel', not discussing all possible types of trapeziums while talking about right angles contained in a trapezium, etc., can be looked at from the perspectives of missed opportunities as examples of case 1 of the framework, wherein the teacher doesn't notice the contingency in a mathematical situation. It is a matter of active pedagogical choice for teachers to respond to or build on the incorrect utterances and doubts raised in class. The ideas of teacher's discretion and autonomy in making pedagogical choices are important aspects of the profession. In the absence of a robust system for teacher education in the country, can we always pose such an argument in the favour of educators? This section investigates two instances of teacher-student interactions.

Scenario 1

The teacher had been teaching the chapter on quadrilaterals for the past 4-5 mathematics lessons. This class started with a recap of the previous topic, types of quadrilaterals. Towards the completion of the recapitulation, the teacher asked students to frame questions to distinguish between quadrilaterals, based on their properties. Students were divided into two subgroups as boys and girls, and each sub group had to ask questions one after the other. The other group was supposed to answer the posed question and the teacher intervened and moderated turns. The following extract is taken from one such teacher-student interaction of about 7-8 minutes.

1	S_b	Why is none of the angles of a kite a right angle?
2	T	Who will answer this question? Now, try this in the matchstick shapes[1] that you have made.
3	T	Try making a right angle.
4	S_{g1}	Sir, a kite is being formed.
5	S_{g2}	It has become a trapezium.
6	T	No, a scalene quadrilateral is formed. Show this on the black board.

S_{g2} brings the manipulative and the teacher copies the shape on the black board.

7	T	Which quadrilateral is formed?
8	S_{g2}	Scalene quadrilateral
9	T	This has to be made into an angle of 90^0. But if we do that, the shape is deformed and no longer will remain a kite. Good question, sit down.

T - Teacher, $\mathbf{S_{b1}}$ - first boy student, $\mathbf{S_{g1}}$ - first girl student

1 – The students had done an activity based on making different shapes (particularly quadrilaterals) using match sticks and cycle valve tubes (a low-cost teaching learning material).

During post-class interaction, the teacher agreed that this possibility had never been explored by him before. This question was clearly not in the lesson image of the teacher, hence a contingency. The teacher thought that the question was dealt correctly using the concrete manipulative. The concerned teacher had even named the most general kind of quadrilateral as scalene quadrilaterals. He realised the mathematical potential in the question and used his transformative knowledge (Rowland et al., 2005) by asking a student to come and demonstrate the construction of a right angle in a kite, through the concrete manipulation of sticks joined through nuts and bolts, and threads hung from these bolts. However, he was not able to drive it to meaningful exploration of the possibilities. The process applied lacked rigor in bringing out the nature of the problem, hence belongs to case three category of the framework. Here, the teacher's noticing goes through the steps of attending, interpreting and responding, yet doesn't do justice to the problem, probably due to dependency on physical construction of right angle in a kite, a case of inductive method, or verification. This problem is at vanHiele level 3 (abstraction) (Manizade & Mason, 2010) because students engage with the definition of kite and the existence of right angle(s) at least requires informal arguments to justify. There is no attempt to generalise this notion for the entire set of kites, a problem pitched at level 4 (deduction).

Scenario 2

Another such teacher-student interaction from the same lesson is presented below:

1	T	Now, tell what a parallelogram is.
2	S_{g1}	If we change all the four angles of a rectangle, it becomes a parallelogram.
3	T	Any other answers?
4	S_{b1}	All of its angles are 90^0.

T repeats the sentence said by the student in a dissatisfied tone giving negative reinforcement.

5	S_{b2}	The opposite sides are equal.
6	T	This property is held by rectangle, square and rhombus. How can we tell then?
7	S_{g2}	That which has opposite lines equal and parallel.
8	S_{g3}	Whose difference of the lengths of the sides are equal.
9	T	Means you are saying that the opposite sides are equal. Think some more.
10	S_{g4}	A quadrilateral that has its opposite sides parallel but angles not equal to a right angle.
11	T	Yes, very good.

This situation also concerns vanHiele level 3 (abstraction) as it involves perceiving relationships between properties, creating meaningful definitions, and justifying through arguments. It is also concerned with level 4 (deduction) due to the inclusion of ideas of necessary and sufficient conditions for the construction of a parallelogram. The teacher appreciated response from S_{g4} and ended the conversation legitimizing only her definition of parallelograms as 'correct'. It appears that the teacher was looking for a specific definition of parallelograms as he ignored the previously related responses by S_{g1}, S_{b1}, S_{b2}, S_{g2}, and S_{g3}, without meaningfully engaging with any of them. The teacher does not attend to the mathematical details (Jacobs et al., 2010) in these responses. Some of the equivalent definitions of parallelograms could have been taken up as subjects for exploration before moving onto the next question. Hence, it is a case of missed opportunity due to non-realization of potential for mathematical inquiry, hence, case two. However, in a stricter sense, this situation does not qualify as contingent, as the teacher thought that all the responses fell within his observations space (Rowland & Zazkis, 2013).

S_{g1}'s response appears to be shaped by the students' experience of manipulating different geometric shapes using matchsticks (a learning aid). With this material, pressing the opposite angles of the rectangle always yields a parallelogram. Theoretically, the angles of rectangle can be changed in many different ways and only a particular combination of such manipulation yields a parallelogram. Different such combinations of ways of manipulation could have been explored here for building deeper understanding. The response of S_{b1} (all right angles) again indicates the use of specific types of parallelograms (rectangles), which was neither challenged nor built upon by the teacher. The definitions provided by S_{b2} and S_{g2} are mathematically consistent and form a case worthy of acknowledgement and taking up for discussion by the teacher. The emphasis on the acknowledgement and exploration of the multiple definitions resonates with the view, "Saving school mathematics from the tyranny of one correct answer" (National Council for Educational Research and Training [NCERT], 2006, p. 6). Student S_{g3}'s response is complicated and could have been understood further only through probing questions, hence a missed opportunity. The teacher oversimplifies the statement and reduces it to the response given by student S_{b2}. Student S_{g4} quotes the standard definition provided in textbooks but she adds this additional condition about each angle not being equal to the right angle. This is a Partition definition (De Villiers, 1994) that excludes rectangles and squares as special cases of parallelograms. Although some of these definitions could only be proved through formal deduction using the concept of 'congruence of triangles' (a topic introduced later in the curriculum), nevertheless, these can provide students avenues to verify and explore necessary and sufficient conditions, to understand mathematical invariances (class of quadrilaterals, parallelograms, in this case) in mathematics.

SUGGESTIVE EXPLORATIONS

We have tried to build on the analysis of teacher responses to propose possible explorations aimed at reorganising (Sherman, 2010) children's thought processes about relationships between properties of the above discussed quadrilaterals and the necessary and sufficient conditions involved, by using GeoGebra. Although given as procedural steps, these are indicative approaches that can be followed for verifications, understanding need for mathematical proof and developing it. We noted that students needed to be given opportunity to construct own steps of construction using GeoGebra tools before they were guided through ready-made procedural steps. Such an approach was better disposed towards the expressive nature (Sherman, 2010) of students' mathematical goals. The activities proposed are of type 2 (Developing Abstraction) and type 3 (Developing Deduction) (Manizade & Mason, 2010).

Scenario 1: Exploration of Kites

Kites can be mathematically defined as 'quadrilaterals with two pairs of (disjoint sets) equal adjacent sides. This partitive definition does not include rhombuses and squares as special cases of kites. Another possible definition can be 'quadrilaterals with two pairs of equal adjacent sides. As a consequence of this inclusive definition, rhombuses and squares can be included to be considered as special cases of kites. Hence, squares can be considered as cases of kites having four right angles simultaneously, or rhombuses as kites having all equal sides. However, the partitive definition can be used to deal with the other two cases where a kite has right angles. Kites have one pair of opposite angles equal and another pair of opposite angles that are unequal. These properties give rise to two possibilities – first, the pair of equal opposite angles can simultaneously be equal to right angles and second, one of the unequal pairs of opposite angles can be a right angle.

To guide students towards exploration of these possibilities, one can start by taking rhombus as the limiting case. We can either stretch or push inwards one pair of adjacent sides of the rhombus, along the diagonal that is not bisected by the other diagonal using sliders in GeoGebra. This process of manipulation transforms (in abstract) or manipulates (with a concrete model) the rhombus into kites. In this process of manipulation, one can use protractors with concrete models to arrive at kites that have the equal opposite angles as right angles. A dynamic software environment like GeoGebra can also provide students an opportunity for such explorations. The snapshots of two cases of kites having right angles is shown in Figure 1.

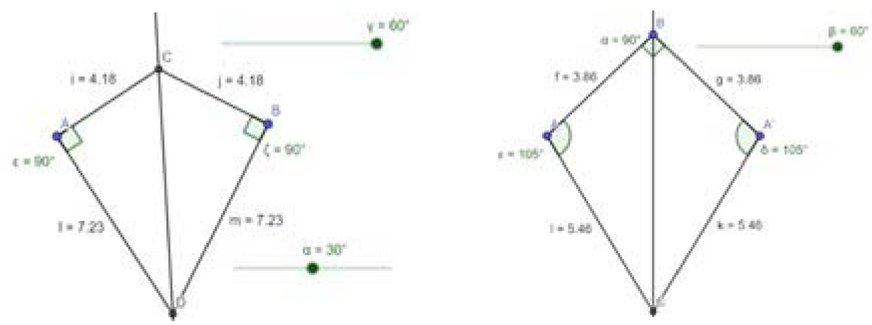

Figure 1: Right angles(s) in Convex Kite

A dynamic environment can help students verify other properties and invariances resulting out of such restrictions. The first image in Figure 1 is the case of a 'right kite' formed from two congruent right triangles as can be proven using the RHS criteria of triangle congruence. This is also a cyclic quadrilateral, since both pairs of opposite angles are supplementary. A square can be understood to be a right kite with equal diagonals. A right kite can never be a concave quadrilateral as the reflex angle and the two right angles will sum to more than 360^0, degenerating the quadrilateral itself. The second image in Figure 1 is the case of a kite having one right angle. This kite can be manipulated into a concave quadrilateral as shown in Figure 2.

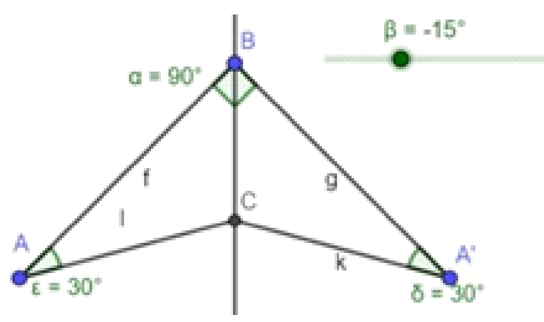

Figure 2: Right angle in Concave Kite

Multiple definitions of parallelograms exist depending on the type of restrictions that are imposed on quadrilaterals. The beauty of the same invariance resulting from the imposition of different restrictions can provide students with interesting opportunities for mathematical exploration. Eight possible definitions of parallelograms have been discussed in this section, out of which three (Definitions 1, 3, and 6) were mentioned by students in the classroom scenario. The definitions and steps for exploration, along with relevant GeoGebra snapshots, have been listed below one by one.

Quadrilaterals with both pairs of opposite sides parallel.

Draw two arbitrary intersecting lines *AB* and *AC* using the Line tool as shown in Figure 3. Now, draw a line through point *C* which is parallel to line *AB* and another line through *B* which is parallel to line *AC*, using the Parallel Line tool. Mark the point of intersection of these two lines through points *B* and *C* as *D* using the Intersect tool. Through a *drag test*, the quadrilateral *ABDC* can be verified to be a parallelogram through its properties.

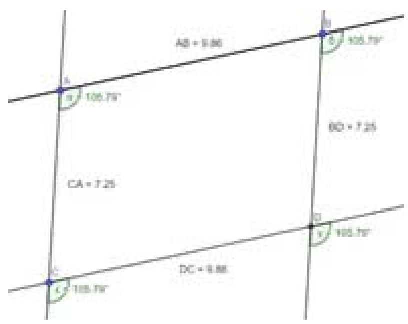

Figure 3: Definition 1

Quadrilaterals whose diagonals divide them into two congruent triangles.

Draw a triangle *EFG* using the polygon tool. Find the midpoint *H* of the side *EG* using the midpoint tool. *EFG* using the polygon tool. Rotate triangle *EFG* about point *H* by 180^0 to get triangle *E'F'G'* using the Rotate around Point tool. Quadrilateral *EFGF'* thus formed is a parallelogram as shown in Figure 4.

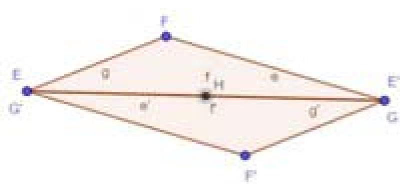

Figure 4: Definition 2

Quadrilaterals with both pairs of opposite sides equal.

Draw two intersecting lines *AB* and *AC* using the Line tool. Now, draw a circle *c* with centre as *C* and radius as *AB* and another circle *d* with centre *B* and radius as *AC*, using the Circle with Centre tool. Mark the point of intersection of the circles *c* and *d* as *D* using the Intersect tool. Join line segments *BD* and *DC* using the Segment tool. Quadrilateral *ABDC* is a parallelogram as shown in Figure 5.

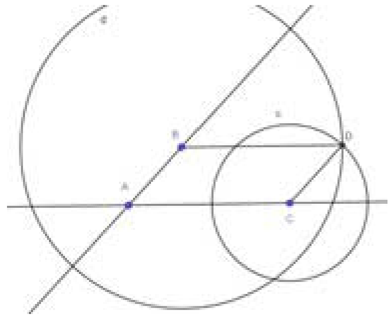

Figure 5: Definition 3

Quadrilaterals with both pairs of opposite angles equal.

Create two angle sliders

α and γ with range 0^0 to 180^0 using the tool. Draw an angle *ABA'* with size as α using the tool. Take an arbitrary point *C* on side *BA'*. Create two angles *BCB'* and BAB'_1 with size γ using the tool. Mark the intersection point of lines *CB'* and AB'_1 as *D* using the tool. Mark the angle *CDA* using the tool. Now, use the *drag test* to see for what values of α and γ does the quadrilateral *BCDA* become a parallelogram as shown in Figure 6.

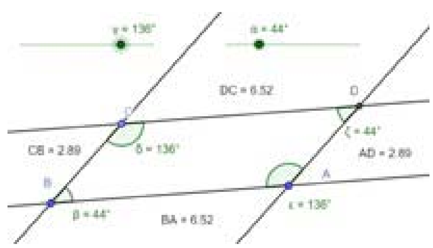

Figure 6: Definition 4

Quadrilaterals whose diagonals bisect each other.

Draw a line segment AB using the Segment tool, and find its midpoint *C* using the Midpoint or Centre tool. Then, draw a line segment *CD* of an arbitrary length using the Segment tool. Rotate line segment *CB* by 180^0 using the Rotate around Point tool and join the four end points *ADBD'* to get a parallelogram as shown in Figure 7.

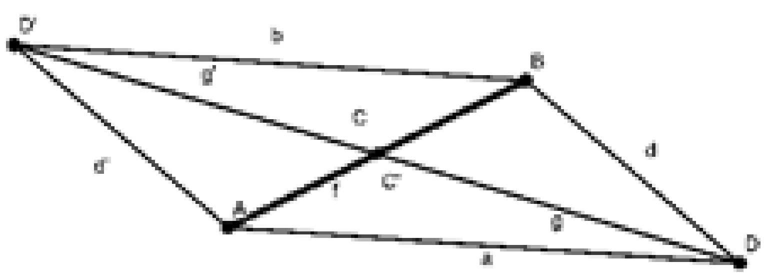

Figure 7: Definition 5

Quadrilaterals with one pair of opposite sides equal and parallel.

Create a number slider *a* with range 0 to 5 units using the Slider tool. Draw two line-segments *AB* and *CD* of length *a* using the Segment with Given Length tool. Draw a line through point *D* parallel to segment *AB*, using the Parallel Line tool. Drag point *D* manually to make the segment *CD* become parallel to segment *AB*. Join points *ABDC* using the tool to get a parallelogram as shown in Figure 8.

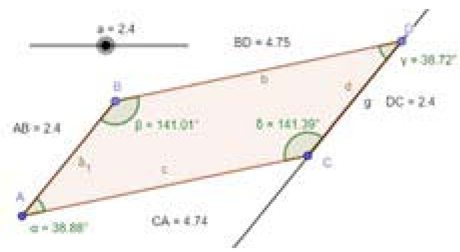

Figure 8: Definition 6

Quadrilaterals with a pair of opposite sides parallel and a pair of opposite angles equal.

Draw a line *AB* using the Line tool. Draw a line *g* parallel to *AB* that passes through an arbitrary point *C* using the Parallel Line tool. Join points *A* and *C* using the Segment tool to make a transversal to the parallel sides. Mark angle *CAB* using the Angle tool as *á*. Choose an arbitrary point *D* on line *g*. Draw an angle *CDC'* equal to á in the clockwise direction, using the Angle with Given Size tool. Draw line *DC'* using the Line tool. Mark point *E* as the intersection point of lines *AB* and *DC'* using the Intersect tool. Quadrilateral *ACDE* thus formed is a parallelogram as shown in Figure 9.

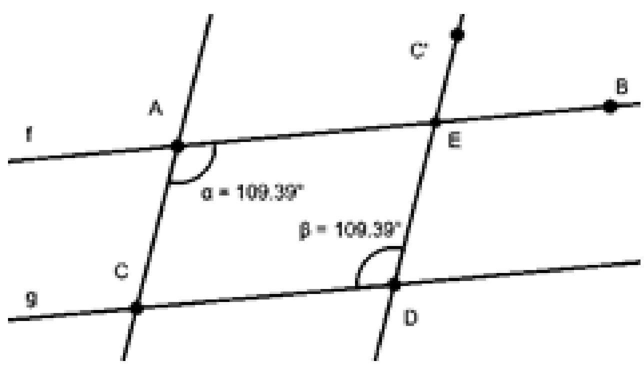

Figure 9: Definition 7

Quadrilaterals with one pair of opposite sides equal and one pair of opposite angles equal.

This definition seems to flow naturally from some of the above explored statements. A preliminary exploration in GeoGebra also seems to verify/confirm this conjecture. However, such a parallelogram cannot be uniquely determined. To falsify this statement, we require to construct just one counter-example, as shown in Figure 10. *BQ* and *BD* are radii of the same circle. Triangle *ABQ* has been rotated about point *B* such that *BQ* coincides with *BE*. This triangle is then reflected along the segment *BE* and the resulting triangle is again flipped about the perpendicular bisector of *BE*. Quadrilateral *ABCE* thus formed has equal opposite sides *AB* and *CE* and equal opposite angles *A* and *C*, yet it is not a parallelogram. Hence, this statement is falsified and rejected as an invalid definition.

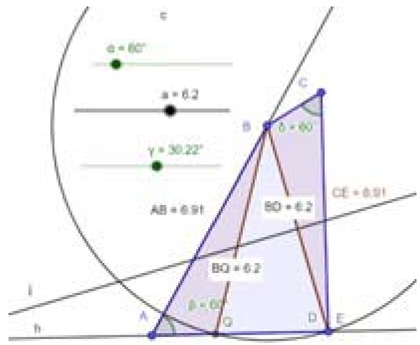

Figure 10: Definition 8

LIMITATIONS

The student participants could not be interviewed for this research. There are times when teachers took an informed choice of postponing the elaboration of a concept during a lesson. The two instances discussed in this paper have been taken from a classroom quiz activity wherein the scope of deviations from the set-out agenda is limited by design. The teacher's active facilitation made the contingent situations possible. The analysis may not only be seen as a critique but as inputs for considerations for teacher support, especially in teachers' noticing of geometric reasoning lessons. Moreover, the discussion on the framework remains incomplete in the absence of a fourth case of the framework.

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INCORPORATING STEAM PEDAGOGY IN TEACHING MATHEMATICS

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Mathematics has been considered as an important discipline since ancient era. Teaching mathematics was taken as a prestigious job. Mathematics was considered as a source for creative and critical human resource. Over the period of time, teaching and learning Mathematics, mostly in school levels, is confined to transferring "official knowledge" from teachers' head to students' head. The overemphasis on procedural mathematical knowledge and major focus on routine problems have served the narrow interest of limited people who have been viewing mathematics as the subject of deposition of pre-defined knowledge and skills. There could be various reasons behind such scenarios. One of the reasons is inadequate teachers' knowledge and skills in the Nepali context on using innovative pedagogical practices. In this regard, this research was conducted to help teachers prepare and implement the various STEAM projects (inquiry-based projects, stories and poems, technology-enhanced teaching and so on) in mathematics teaching. The Participatory Action Research (PAR) was used in two different schools of Kavre district in the rural parts of Nepal. The specific problems were collectively explored after a series of consultative meetings, and the intervention plans (making projects) were developed together and implemented in the classroom. Through a series of reflections on/in the process, it was found that the motivation of students towards mathematics learning increased, and the engagement of the students in mathematics classroom was meaningful. This paper aims at sharing the needs of the research, methodology, and major findings and conclusions.

MATHEMATICS TEACHING IN THE NEPALI CONTEXT

Elsewhere, Nepali educators, Luitel (2013, 2019), Shrestha (2018), and Pant (2015, 2019) have illuminated the state of mathematics teaching in the Nepali context which is more decontextualized and disengaged in nature. Going back to the needs of subjects like mathematics, the Ministry of Education, Science and Technology (MoEST) has repeatedly mentioned that mathematics is the foundation for other subjects. The school level mathematics curriculum is largely aligned with the notion of 'curriculum as subject matter' (Schubert, 1986). The purpose of such a notion of curriculum is to prepare children having mastery in subject matter with very limited skills in dealing with real-world complex problems. The present mathematics textbooks provide a series of mathematical problems that normally do not represent the actual problematic context of life that can create rich learning experiences among school students. The students are forced to memorize the knowledge and demonstrate the limited skills in a discrete setting, thereby producing procedural understanding of subject matter (Baker, Czarnocha, & Prabhu, 2004). Over the period of time, such practices created disciplinary egocentrism (Connor, Karmokar, & Whittington, 2015) among students and teachers that normally does not allow them to think outside their disciplines. The disciplinary egocentrism is a state of thinking and performing certain tasks where a person is hegemonized with the particular disciplinary knowledge system and ways of developing such knowledge. Such a situation does not welcome multidisciplinary and alternative ways of knowing and performing.

On the one hand, the school education envisages producing empowered citizens who can solve complex real-world problems. On the other hand, the majority of school teachers still take different subjects (such as Mathematics, Science, Computer, Social Studies, etc.) as completely separate entities. We forget that all the subjects at school level are to prepare children to deal with their daily life problems and develop the foundations for higher studies. For this, children should be at the centre, and different subjects should be considered as a means of achieving the goals of education. An influential educator, Palmer (2017), has stated that instructors who refuse or are unable to see students as whole persons, with intellectual capacities and emotional vulnerabilities, may lack an ability to "see" their own strengths. His thoughts also align with the ideas of integrated approach of teaching and learning where the children are viewed as whole and capable social beings. A recent study of Education Review Office, a government body, has found unsatisfactory results in Mathematics nationwide (ERO, 2017). Out of various reasons, the overemphasis on fragmented teaching and learning activities was noted.

STEAM PERSPECTIVES IN SCHOOL EDUCATION

One of the problems of school education in Nepal is the overemphasis on the content that is presented in a more segregated manner in each subject. Teaching Mathematics, Science, Technology and Arts with different approaches keeps the subjects in isolation, and they are treated differently as they exist separately without any kinds of interconnections. The real-world problems require knowledge and skills from multiple disciplines. If we are asked to solve our personal, social and professional problems (such as building a model of a house, fixing the carpet at home, painting the walls, etc.), the ideas should be drawn from different areas (Mathematics, Science, Technology, Engineering, etc.) in many cases. For example, if a student is asked to develop a model of a house, she/he has to use various knowledge and skills from different subject areas; designing ideas from engineering perspectives, calculation from mathematics, use of different available materials from the perspectives of contemporary society, scientific perspectives from Newtonian science perspectives, and more than that creativity from artistic perspectives.

Working in the field of teacher education for more than a decade, we experienced that the connections among different subjects and within the contents of the same subject are not well covered and recognized. Such practices could not promote the holistic way of knowing. In this regard, treating a child as a whole and integrating more than one concept from different disciplines in a more critical and creative manner are urgent in our education system. To address such problems in school education, STEAM (Science, Technology, Engineering, Arts and Mathematics) education is gaining popularity these days around the globe. STEAM is an integrated and interdisciplinary approach to learning that encourages students to think more broadly and critically about the real-world problems. In this approach, the real-world problems are solved by incorporating the scientific, mathematical, engineering and technological knowledge in a creative way. It does not mean that every problem needs all the dimensions to address but it normally requires more than one area to explore the better solutions. For that, our traditional “subject-centric” approach of teaching and learning is unhelpful and disempowering.

The idea of STEAM education has been proposed to promote productive engagement among the learners in issues and problems associated with science, mathematics and related curricular areas (Stroud & Baines, 2019). STEAM education puts primacy on integrated curriculum and pedagogy so as to use knowledge and skills in creative and imaginative (i.e. artistic) ways. The ‘A’ in STEAM education is helpful to address the unaccounted approaches to integration. For example, arts-based methods (painting, building models, story-telling, singing, etc.) help teachers and students connect various disciplinary skills of science and mathematics. Another important feature of STEAM education is to practice the idea that school is a place for the “production” of knowledge. Here, the notion of production is political and for the betterment of society. This helps to replace the conventional lecture-based pedagogy through a series of carefully designed sessions in which students actively engage in exploring, analysing, evaluating, and creating something useful and related to their academics. By enabling learners to create something new, it may increase the engagement of learners in the educational processes.

STEAM education engages students in transformative learning that promotes the interconnected ways of knowing such as cultural self-knowing, relational knowing, critical knowing, visionary and ethical knowing, and knowing in action (Taylor, 2015). Keeping the notion of STEAM related skills (science process skills, manipulative skills, computational thinking skills, reasoning skills, engineering design thinking skills and ICT skills) at the centre, the courses in the school level can be designed accordingly, which can be taught using an inquiry-based approach, project-based learning and digital learning. Inquiry-based approach promotes STEAM disciplines to enable students to engage in authentic and meaningful activities that help to improve reasoning skills. The project-based learning enables students to develop 21st century competencies including resilience, coping with uncertainty, self-reliance, and creativity by interacting with the real-world activities. The digital learning is a modern learning environment that enables students to develop their technological literacy and critical thinking skills throughout their daily learning activities. English (2016) also argues that a greater focus on STEM integration is needed with a more balanced focus on each of the disciplines.

PURPOSE OF THE STUDY

The purpose of this study was to explore the innovative pedagogy that contributes to the enhancement of the performance of teachers and students. More specifically, the researchers were interested in collaborating with school leaders and mathematics teachers to develop and implement the STEAM pedagogy from the perspectives of integrated learning approach as per the needs of the context.

THEORETICAL POSITION

As teacher educators, after a long journey in identifying well-known theories of our field, we came to realize that there is no “royal road” to pedagogy, and grand theories of teaching and researching may not be appropriate in developing ourselves (and teachers) as change agents. Hence, we believe in home-grown theory (i.e. theory which is locally developed to serve the needs of the local context) in pedagogical worldviews. In this context, Transformative Learning Theory which is rooted in the work of Mezirow (1991) and Living Theory Methodology (Whitehead, 2008) were very much helpful for us in this study.

On the one hand, Transformative Learning Theory provided us as researchers with a new epistemological ground in research that advocates research as a means for transformative learning. It helped us, as citizens of non-Western societies, to assess our false consciousness on the so-called dominant theories of education and learning, where the influence of the neocolonial thinking is increasing day by day (Pant, 2019). Moving forward to what Mezirow (1991) proposed as Transformative Theory, we used the ideas of Dirkx (2012), which values the integrated approach to transformative learning grounded in a concept of multiple 'selves' that recognizes the importance of both the rational and affective, and the personal and the social dimensions in fostering self-understanding. On the other hand, Living Theory Methodology always reminded us of the most important question raised by Whitehead (2008), "How do I improve what am I doing?" Whitehead (2008) explained that a living theory is an explanation produced by individuals for their educational influence in their own learning, in the learning of others and in the learning of the social formation in which they live and work. For us, these theories were supporting to have deeper view of the world of our research and practice.

RESEARCH METHODOLOGY

We, researchers, claim that we conduct research for the betterment of the society. But, it is hardly seen that the researchers involve research participants to share their voices in all stages of the research process. However, as PAR (Participatory Action Research) researchers, we believe that young and adult people should be able to articulate their views on issues that matter to them, and their views should be valued in accordance with their age and maturity (Lansdown, Jimerson & Shahroozi, 2014). Moreover, PAR model provides such opportunities where a researcher acts as an activist-scholar (Mirra, Garcia & Morrell, 2016), and ordinary people are enabled to play an active and influential role in decisions which affect their lives, meaning that their voices are not only heard but also addressed throughout the research process. Rather than the objective interpretation of an outsider, PAR demands insider participation that illuminates the problem under the study (Padilla, 2014) and is conducted under a collaborative research team that utilizes dialogue and reflection during all phases of the research process. The PAR research design creates a set of interconnected opportunities where conversations about teaching and learning take place with a lot of innovations in curriculum, pedagogy and assessment. In this regard, we adopted the PAR approach so as to engage the teachers, students and community members in the development of innovative strategies to improve the performances of both the teachers and schools.

Most importantly, PAR aims to develop critical consciousness about the research agenda and research process to improve the lives of those who involve in the research process, and to transform fundamental societal structures and relationships. Park (2001) calls PAR the research of the people, by the people, and for the people. In our research context, 'people' are students, teachers, teacher educators and community people. In this regard, we also felt that PAR could be an appropriate research methodology to serve our interest to bring some notable shifts in the present pedagogical approach. There are various steps to be followed in PAR methodology. The principles behind such steps are democratic, equitable, liberating, and life-enhancing qualitative inquiry that make it distinct from other qualitative methodologies as noted by MacDonald (2012). We chose two different schools and worked with four teachers who teach mathematics till grade eight. During the phase of needs identification and sharing, we also invited head teachers and the community members. The first step was to identify the needs of the school teachers.

Based on our experiences as teacher educators, we felt that incorporating STEAM pedagogy in school mathematics is one of the needs of the school education at present. But the needs of the teachers in the research site could differ from our assumptions. That's why, the "real" needs were identified after conducting one workshop, two interviews and one participant observation with school teachers, leaders and community members. This was a collective task in PAR. After conducting workshops, we developed a plan of actions. The school teachers shared that students were demotivated in mathematics class, and the problems of textbooks were not contextual. The head teachers were expecting supports for school teachers to prepare rich tasks in mathematics. The community people shared that their kids found mathematics very difficult.

BEING IN THE FIELD

The capacity building of teachers on the chosen strategy was the most important aspect in this study. Both the capacity building of the teachers and the implementation of the skills they developed during the workshop sessions, went together. We planned for three cycles – each cycle of one month. Our intent was to improve our plan after the completion of the first cycle as per the spirit of PAR. The first cycle aimed at reflecting teachers' practices and helping them to develop inquiry-driven mathematical tasks, which was the foundation for STEAM pedagogy. The second cycle aimed at preparing and implementing STEAM projects, and the third phase was for updating the projects based on the feedbacks and reflection of the first and second cycles, and reflecting the entire process and the outcomes at the end. In doing so, a two-day workshop was conducted at the beginning of each cycle and teachers were asked to implement the tasks/projects prepared in the workshop for the rest of the days. We, as researchers, provided ample support to implement the projects in the class, and we all collaboratively (with school teachers) explored the solutions to the problems that arose during the implementation. Regular follow-up and feedback sessions were also organised in the schools.

In the workshop of the first cycle, the teachers were asked to reflect on their practices. The researchers used the principle of transformative learning to make them realize their assets and limitations as mathematics teachers. The 'asset' was about eagerness to learn new things and the 'limitation' was about the deeply-rooted beliefs and practices in traditional ways of teaching mathematics (i.e. lecturing the ideas, solving the problems on the whiteboard, and giving routine-based problems as homework). The inquiry approach in mathematics lessons was discussed and some inquiry-driven tasks were developed in the workshop. When mathematics teachers implemented those tasks in the class, they were asked to share their experiences. The good part was that almost all the teachers shared that the tasks helped to develop conceptual knowledge and understanding of mathematics. For example, in one of the tasks, a teacher asked students of grades six to prepare a budget of their family. This particular task provided rich environment to learn about the family income, expenditures and the expense headings. One of the students shared that the majority of expenses had to be allocated in health and education. This cycle created a good foundation for us to move forward to preparing STEAM projects.

Moreover, we have taken STEAM more than an acronym for Science, Technology, Engineering, Arts and Mathematics. STEAM is an innovative pedagogical approach in which scientific thinking is derived from science, logical thinking from mathematics, design thinking from engineering, arts-based pedagogy from arts, and technology-enhanced pedagogy from technological perspective. So, in the second cycle, the teachers were asked to develop projects by using those various perspectives (one or more) in teaching mathematics. In this cycle, one teacher prepared a project named as *mathematics in the kitchen* where he tried to teach basic operations of mathematics (addition, subtraction, multiplication and division) with the examples of stuffs which are used in the kitchen. Another school teacher prepared a project named as *mathematics of the carpenter* where he taught measurement related ideas by connecting with the practices of carpenter. The purpose of such activities was to improve teachers' own practices as Whitehead (2008) suggested asking the question to oneself: "How do I improve what I am doing?" Finally, the teachers implemented their plans accordingly and shared their insights.

In the third cycle, the teachers were updated with their projects based on the insights received from the first and second cycles. Some teachers were guided by scientific inquiry model while updating the projects while the others had their focus on technology, different forms of arts (stories and cases) and design thinking. In this cycle, the teachers gradually prepared few stories to capture the past events of the community. One teacher started to use mobile set to demonstrate the various geometrical objects. Another teacher asked students to draw their dream house with the appropriate measurement. These activities provided rich experiences for students. At last, the community people also shared the changes they observed in the students and teachers and the practices.

REFLECTION AND LESSON LEARNT

Reflection and lessons learnt were iterative and bi-directional throughout this research study. The reflection part was an ongoing process since the time we started interacting with school teachers, students and other stakeholders. During the process, we always emphasized the critical reflections on our deeply-seated beliefs, practices and ideologies. We observed that the overemphasis on disciplinary approach of school education was unhelpful to develop students as a holistic human being with enough human and social values and integrities. If we prepare rich teachers' professional plan that supports teachers in their workplace, it will be much beneficial to all the stakeholders (students, teachers, school and community). The study successfully demonstrated that teachers were able to develop and implement the projects. The performances of the students also improved, and more than that they were found motivated in learning mathematics meaningfully. The performances of the students were measured through a rubric developed by school teachers. In the rubric, the scores of class tests, interaction with teachers and students, attentiveness, and timely completion of the projects were mentioned. During the research study, we found the ideas of Spivak (2003), who has been ignoring the standardized "rules" of the academy and advocating moving forward from the disciplinary boundaries, much empowering and helpful in our context. Based on our research study and experiences, the conventional disciplinary values and such mind-set have been creating a narrow and disempowering space in school education. That's why we conclude that the innovative STEAM pedagogy should be incorporated in teaching mathematics through STEAM education in Nepal.

Note: This paper is based on the research conducted by the first author. The second author is the supervisor of the first author. The third author is the "critical friend" of the researcher who offered critical suggestions during the field work, and writing phase.

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TEACHERS' PERCEPTION ON IMPLEMENTING HOTS IN SCIENCE EDUCATION

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The recent attempt of reformation of the Indian education system aims at assessing learners' abilities from all aspects. The concept of HOTS has lately been introduced in the evaluation and examination process (CBSE, 2010). The entire process of students' evaluation requires rigorous skills and training on the parts of teachers. Hence, it is of utmost importance to consider teachers' views regarding any new change. This paper is an attempt to study science teachers' perceptions towards implementation of HOTS in the evaluation process of science education. A survey was conducted to determine their perception about HOTS implementation with respect to four variables viz.; need, clarity, complexity and quality and practicality.

INTRODUCTION

The curriculum is decided based on the changing needs of the society. With the changing needs the evaluation patterns also should be reformed. Document of the National Policy on Education (MHRD, 1986) expressed an aspiration that science education would be strengthened so as to develop in the child well-defined abilities and skills such as spirit of inquiry, creativity and objectivity. Since examinations are an indispensable part of the educational process as some form of assessment is necessary to determine the effectiveness of teaching-learning process and their internalisation by learners (CBSE, 2010), use of varied modes of assessment are desired to shift the focus of the exams from testing memory to testing higher levels of competencies (NCERT, 2005). Reform in examination is need of the hour because the quality of question papers is low. They usually call for rote-memorisation and fail to test higher-order skills (NCERT, 2006). One such reformation is introduction of Higher Order Thinking Skills (HOTS) questions in secondary education. Central Board of Secondary Education (CBSE) took this remarkable step to shift the focus from assessing students' mere crammed information to developing their higher level competencies.

Implementation: a momentous coupler

Any new policy or a plan is put forward with an objective to propel the process of change. According to Fullan (2007) there are three broad phases of the change process:

Phase I—variously labelled initiation, mobilization, or adoption—consists of the process that leads up to and includes a decision to adopt or proceed with a change; Phase II—implementation or initial use (usually the first 2 or 3 years of use)—involves the first experiences of attempting to put an idea or reform into practice and; Phase III—called continuation, incorporation, routinization, or institutionalization—refers to whether the change gets built in as an ongoing part of the system or disappears by way of a decision to discard or through attrition (Berman & McLaughlin, 1977; Huberman & Miles, 1984). (p. 65).

The following figure illustrates the change process explained by Fullan (2007):

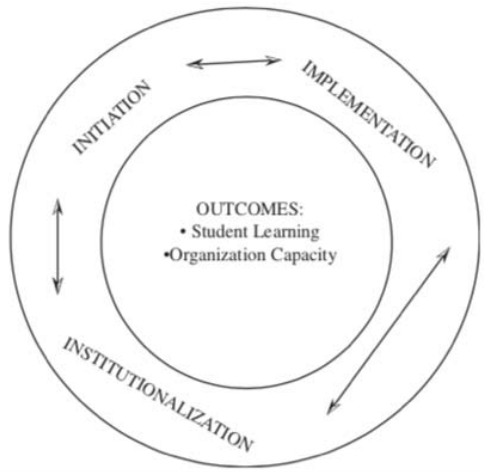

Figure 1: A simplified overview of the change process (Fullan, 2007)

It can be inferred from the above explanation that implementation is the momentous coupler of phase I i.e. initiation and phase III i.e. institutionalization. In Fullan's (2007) words, Implementation consists of the process of putting into practice an idea, program, or set of activities and structures new to the people attempting or expected to change. The change may be externally imposed or voluntarily sought; explicitly defined in detail in advance or developed and adapted incrementally through use; designed to be used uniformly or deliberately planned so that users can make modifications according to their perceptions of the needs of the situation (p.84).

Implementation, further, is characterised by four variables: "Need, Clarity, Complexity and; Quality and Practicality" [Fullan (2007), p. 87]. Huberman and Miles (1984) explain that people involved in the implementation stage must perceive the significance of the needs and must make some progress towards meeting those needs. Clarity, on the other hand, is crucial in the implementation phase since "lack of clarity - diffuse goals and unspecified means of implementation—represents a major problem at the implementation stage" [Fullan (2007), p. 89]. Complexity requires making change in one's self, carefully chosen set of activities and understanding of the big picture [Fullan (2007), p. 91]. Lastly, quality and practicality are affected by various factors such as materials and resources and; development in people's minds and actions count here [Fullan (2007), p. 92].

In the present paper, "the people attempting or expected to change" [Fullan (2007), p. 84] are the secondary school science teachers. The outcome from students' HOTS development can be achieved by the active role of teachers in planning, implementing, and evaluating HOTS-oriented learning. To be able to plan HOTS-oriented learning, teachers need knowledge of ways, strategies and methods to train students about HOTS (Bartell, 2012). Therefore, teachers' role is pivotal in implementing any new change or reform. The question of concern here is how far the teachers, who are supposed to be the pillars of implementing the proposed plan, are well versed with the underpinnings of putting the proposal into action.

OBJECTIVE OF THE STUDY

To Study teachers' perception of implementation of HOTS in science education.

Research Questions

Following research questions were framed to study teachers' perception.

1. What is the need of implementing HOTS in science education?
2. What is the extent of clarity regarding implementation of HOTS in science education?
3. What complexities do they face during implementation?
4. What are their views about quality and practicality of implementing HOTS in science education?

Methodology

A semi-structured interview schedule was prepared based on the characteristics of change given by Fullan (2007) viz., Need, Clarity, Complexity and Quality and Practicality. There were 15 questions in the interview schedule. 10 science teachers (7 females and 3 males; 1 government school teacher and 9 private school teachers; 5 biology, 3 Physics and 2 Chemistry teachers) of secondary schools affiliated to Central Board of Secondary Education (CBSE) were interviewed. They all were in the age group of 27 - 47 years having qualification M. Sc., B. Ed. They all had teaching experience of 2.5 to 24 years. Seven teachers were interviewed in face-to-face mode whereas three teachers were interviewed in telephonic conversation. Their responses were noted down and later analysed to draw the findings. The teachers will be referred to as T1, T2,…,T10 from here onwards.

ANALYSIS AND FINDINGS

The responses of the teachers were analysed and the emerging themes for each research question are described below:

Need

The following three questions were asked to the teachers regarding the Need variable of implementation.

1. To what extent do you feel/perceive that the need of HOTS in science education is obvious?
2. Why do you feel it is needed to include HOTS in science education?
3. What progress are you making towards meeting the need of HOTS in science education?

On asked about their opinion whether HOTS implementation is needed or not, not a single teacher disagreed with it. All the teachers were in favour of need of implementing HOTS in science education stressing their responses with the words "really important", "definitely needed" and "highly required". However, one teacher

(T7) was of the opinion that "*HOTS is not everyone's cup of tea*".

Various reasons were given by teachers for their opinions. 40% teachers said it was due to application based nature of HOTS questions, 30% teachers had agreed upon HOTS implementation because it brought conceptual understanding in the students, 30% teachers considered need of HOTS obvious for cognitive aspects – increased analytical, logical and reasoning abilities; creative and imaginary thinking, thinking in a divergent way, 20% teachers stated that for widening the views of students and broadening the horizons of the child HOTS implementation was needed. Other reasons for the need of HOTS were: HOTS questions gave a sense of satisfaction to high achieving students since only highly intellectual students would be able to think to that level and; to help a child self-evaluate his performance.

In order to meet the need of HOTS implementation, the following progress was made by teachers: referring various books, identifying HOTS questions and asking those questions to the students (50% teachers), connecting the content to real life situations (30% teachers). T6, interestingly, responded that *applying* HOTS was the progress she made towards meeting the needs of HOTS implementation. T8, on the contrary, opined that nothing new was to be done as she felt that teachers had already been doing all the practices. T3 and T10 asked thought provoking questions and showed models and videos while teaching, respectively, as their progresses. On the other side, T3 twisted the routine questions and made them HOTS ones. For instance, instead of asking "what is resonance?" she asked "a molecule has double bond still it is stable so what is the reason behind it?".

Clarity

Under the umbrella term 'Clarity' following four questions were asked to the teachers.

4. What are the goals of HOTS in science education?
5. What do you do differently to achieve the goals of HOTS in science education? And through what means?
6. How does it help you address the goals of HOTS?
7. What are the prescriptions/ guidelines provided to you for implementing HOTS in science education? In what manner do you follow them? (As it is? Or make changes on your own?)

When asked about clarity of goals following were the responses of the teachers. According to 30% teachers, the goal of HOTS was to improve the creative thinking and improve mathematical applications, understand interrelationship between topics to topics and subject to subject of science, for instance relationship of electromagnetism to optics; HOTS implementation leads to deeper understanding of knowledge and better thinking ability and; it was to make them think because *we need thinkers who can make a difference*. In the view of 50% teachers, the goal of HOTS was application-based problem solving skills, apply the knowledge into real life situations so that the child does not get panicked and; develop higher levels of cognition such as synthesise the knowledge and increase analytical and reasoning abilities. In-depth understanding of concepts was also stated the goal of HOTS by 40% teachers whereas avoiding rote learning and developing interest among students for learning science were stated goals by T8 and T10.

When asked further what they needed to do differently to achieve those goals, the responses given by teachers were more or less the same as stated in response of the previous questions. T1, T2, T6, T9 said they used to read different books and various other material. However, T1 used to frame HOTS questions on his own whereas other three teachers used readily available questions in the reference books. T8 also said that she framed HOTS questions on her own but did not clearly mention about any source of reading material. 30% teachers mentioned about giving multi-sensory experiences using teaching aids such as demonstration method, concept map and practical observations.

To the response of how exactly these practices helped them achieve the goals of HOTS, teachers had diverse views. 50% teachers said that it led to better and deeper understanding of the concepts and deeper interest in science' for T3 it lead to "more interactive class", and for T7 "better involvement in the classroom activities". 20% teachers viewed its utility in preparing students for various exams such as board exams and other competitive exams such as NEET, JEE, NTSE, Olympiad. 20% teachers believed that students got ready to face challenging and thought provoking questions in the class whereas T2 observed better problem solving ability in the students.

When asked about the clarity of guidelines all the 10 teachers had similarity in their responses. They did not have any specific guidelines regarding HOTS. T4, T5, T7 mentioned of CBSE circular which is generic in nature for providing guidelines but no unique document for HOTS is available. The various sources of information about HOTS are NCERT textbooks and private publishers' books. Nevertheless, they do follow the prescriptions given by CBSE for preparing the question papers by differential allotment of weightage to questions of varying difficulties.

Complexity

There were three questions asked to the teachers to determine the complexities faced by them.

8. What changes you have had to make in *yourself* in order to implement HOTS in science education? (in terms of skills required, difficulties faced, alterations in beliefs, teaching strategies, and use of materials.)
9. According to you what series of activities is required to implement HOTS? (is it different than for the previous practices or the same?)
10. So what is the "larger picture" and what is your role in it?

When asked about the changes they had to make in themselves in order to implement HOTS, 50% teachers stated that they had to update their selves from time to time about the news, innovations and latest discoveries in the field of science. T1 had to shift from traditional ways and adopt different skilful ways of teaching, spend more time in framing HOTS questions; T2 had to come out of the textbook and look into surrounding to give real life examples to the students; T3 brought change in teaching strategy and mode of discussion. However, 20% teachers did not see it as something new and hence did not have to change anything in themselves. T10 said that he went through curricula of different countries, their classroom activities, teaching strategies and tried to follow it during teaching.

When probed further regarding the series of activities required to implement HOTS, 40% teachers said change in strategies and use of teaching aids was required whereas 30% teachers considered change in type of questions essential. On the contrary T1 said that not much had changed as previously known as ‘tough’ questions were termed as ‘HOTS’ now. 20% teachers considered that giving varied experiences to students had changed.

Ultimately, when asked about the larger picture and role of teachers in it, all the teachers stated that children were getting prepared to perform better in their future. Through HOTS activities, they could perform better in higher secondary examination, in competitive examinations, could tackle the situations better and could apply their knowledge to real life situation; survive in the competitive world, become good citizens of the nation. All the teachers opined that they played the role of a resource provider and a facilitator to the students. “*Secondary school stage is the training phase for the students*”.

Quality and Practicality

Following five questions were asked to teachers to study their perception about quality and practicality.

11. To what extent do you think that the time given to prepare yourselves for initiation of implementing HOTS was adequate? (the time-line between the decision of implementation and the initiation of implementation)
12. What sort of materials and resources are you provided for implementing HOTS? (high quality teaching and training materials (print, video, electronic))
13. Are you given training for using those materials and resources? By whom?
14. Despite of the materials provided do you make judgements on your own based on students’ performances?
15. What changes has it led to change your *mind* and *action*?

Teachers were asked if the time given to prepare themselves for initiation of implementing HOTS was adequate (the time line between the decision of implementation and the initiation of implementation). In response only one teacher said that it was inadequate and more time was needed to prepare for implementation of HOTS. Rest of the teachers responded that it was adequate. The reasons quoted by them were: “we have been doing it so nothing new is there”, “a teacher has to be ready always and change can come within a fraction of second”.

In the reference of materials and resources provided, 70% teachers replied that nothing from the government was provided to them. Major resources being availed to them were books and laboratory equipment which were supplied by the schools through collaboration with private publishers and suppliers. In addition to that, 20% teachers also mentioned about smart class as a resource being provided by the schools. However, one teacher responded that everything was provided by the government like online lectures uploaded by IIT, books, multimedia resources.

About training for using those materials and resources, 70% teachers were given such training in schools through workshops by private publishers and suppliers. 20% said no training was given to them. One teacher T1 mentioned about workshops, subject enrichment programmes by the government saying that faculties from IIT or other engineering colleges used to come for training.

Despite the materials provided, 90% teachers made judgements on their own. They did make their own judgements while using the materials for teaching, the reasons were: difficult language of the print materials, students' demands, classroom observations, students' performance; continuous assessment and; availability of materials. On the contrary, T10 was of the opinion that not much was needed since whatever is brought to the class, children always like it "They are relaxed that today they don't have to study in routine boring manner."

In the response of changing their minds and actions, all the teachers talked about their changed thoughts, style of working and enrichment attained so far. 30% teachers said that they have become empathetic; competent and a better teacher. 30% teachers said that now they try to make their classes more interactive. T8 was inclined towards including more and more HOTS questions and now focused more on training other teachers as a Head of the Department. T7 felt that she needed to do more and more reading. T9 elaborated the change in his personality. He said that, "*I am ready to face any challenge now. My mind-set is always problem solving based. I don't look at the problem now. I look at the solution*".

SUMMARY AND CONCLUSION

The major responses coming forward again and again are that the teachers strongly agree upon the need to include HOTS in science education and they are making some progress for it. It is to be noted here that all the teachers, in response of one or other question, stated that HOTS implementation is nothing new. They have been practicing it since long in the name of 'tough' or 'application based' questions and hence they do not need to undergo a structural change. Moreover, there is a difference in the opinions of one government school teacher and nine private school teachers regarding trainings and resources. However, the similarity is that all of them do practice HOTS questions during classroom teaching – learning practices.

It can be concluded that teachers possess a "false clarity" (Fullan, 2007, p.89) in their perception about implementing HOTS since they feel that HOTS is nothing new for them. The underlying reasons might be: lack of clear guidelines and of proper trainings and availability of high quality teaching-learning materials other than printed materials. There was a phenomenal convergence in their responses with regard to (i) need of HOTS inclusion, (ii) proper guidelines and (iii) their roles in the entire picture. It is a prominent point to be noted here that the teachers are now well aware about their changing roles. They all stated their roles as facilitators or resource providers. This implies that the aspired reform in the Indian education system of shifting from teacher-centred system to the child centred one is being realised.

On the other hand, there was a huge divergence when they were asked about the change in their minds and actions. It is also prominent that all the teachers have undergone some sort of changes while implementing HOTS in science education though not structural change or change in terms of conceptual understanding of the underpinnings of HOTS. Since implementation is followed by institutionalisation, there has to be a smooth transition of outcomes and ideas attained in the present phase so as to ensure the sustainability of the proposed plan of change. Therefore, it is suggested that teachers do require well-organised trainings in order to understand the significance of the concept of HOTS and implement it in its true sense. Then only it will yield a routinised practice to serve its essential aim of reforming the system.

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SUPPORTING UNDERGRADUATE UNDERREPRESENTED MINORITY STUDENTS FOR SUCCESS IN STEM

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This presentation reports on a model for engaging, retaining, and supporting undergraduate STEM students, and in particular women and underrepresented minorities (URM), which aims at: recruitment of students in the STEM disciplines and in particular URM students; increased persistence of students; increased graduation rates, and shortened time to graduation. The model has been tested and found to be successful at an urban northeastern university in the USA that has been designated as a Hispanic-serving institution. In this presentation, we describe this model, built from support strategies that include mandatory academic advisement; increased exposure to early research experiences; expanded one-on-one faculty mentoring of students; scholarships; robust supporting peer and mentor communities; and we present some preliminary findings.

INTRODUCTION

This presentation offers a model for engaging, retaining, and supporting undergraduate STEM students, and in particular women and underrepresented minority (URM) students. The model has been tested and found to be successful at an urban northeastern university in the USA, designated as a Hispanic-serving institution. The model integrates evidence from psychology, education research, and experience into an effective program[1] for increasing success of undergraduate URM STEM students, and aims to:

a. recruit students in STEM, and in particular URM and female students;
b. increase persistence of students;
c. increase graduation rate, and
d. shorten time to graduation.

In what follows we describe the model for supporting URM students in STEM through mandatory academic advisement each semester; increased exposure to early research experiences; expanded one-on-one faculty mentoring of students; scholarships; and robust supporting peer and mentor communities; and we present some preliminary findings.

[1] The program described here was funded by National Science Foundation grants # 1458714 and # 1930437.

FACTORS CONTRIBUTING TO LOW SUCCESS OF WOMEN AND UNDER-REPRESENTED MINORITY IN STEM

Multiple factors contribute to the low success rate among URM students in STEM. Many undergo a difficult transition to college, and many of them are likely to be first-generation students (Choy et al., 2000, McCarron & Inkelas, 2006). Furthermore, many face challenges in completing introductory science and math courses due to insufficient preparation in high school (Chang et al., 2014) and find the limited interaction with professors disaffecting (Labov, 2004, Gasiewski et al., 2012). Such struggles may be further exacerbated by the perception of the academic environment as unfamiliar and alienating, particularly by women and URM students (Ong et al., 2011; Beasley and Fischer, 2012).

Successful integration depends not only on academic but also on social dimensions of the college (Tinto, 2005). Recent research has shown that STEM persistence is associated with students' ability to cultivate a robust STEM identity (Carlone & Johnson, 2007). It has been found that enculturation into STEM and STEM-related study or career is a part of a process of identity formation (Christidou, 2011). The critical role of STEM identity, related to conceptions of science (Carlone & Johnson, 2007) and mathematics identity (Boaler, William, & Zevenbergen, 2000; Martin, 2000), has been gaining attention among researchers. Recent studies relate aspects of students' self-perceptions as STEM learners and future STEM specialists to competence, performance, and recognition (Herrera et al., 2013). Thus, it has been observed that even high achieving STEM students may struggle to identify with STEM and find connections to their personal goals (Kozoll & Osborne, 2004). On top of these factors, many of these students struggle with considerable financial pressures in paying for college and taking care of their families while earning a degree.

Successful Programs and Models Increasing Success of Students in STEM

There are examples of numerous programs that have resulted in increased persistence, graduation rates, and successful transition to STEM graduate programs or careers. The PEER Led Team Learning Leadership program and the PEERS program at UCLA utilizes academic and career seminars, holistic academic counseling, research seminars, and collaborative workshops for first-year STEM students (Liou-Mark et. al. 2018, Toven-Lindsey et al., 2015). A three-tiered mentoring model was piloted by Ghosh-Dastidar & Liou-Mark (2014) and found successful with URM and female students. Other successful programs like the Meyerhoff Scholars, the Biology Scholars Program at University of California, Berkeley, Gateway Science Workshops at Northwestern University, and the LA-STEM at Louisiana University all share three common interventions widely recognized as successful program components: early research experiences, active learning, and membership in STEM learning communities (Graham, 2013). We have considered all of the above in designing a program to support undergraduate STEM students, particularly women and URM students.

A HOLISTIC MODEL FOR SUPPORTING STUDENTS IN STEM

Considering evidence from research and successfully implemented university programs, we have taken a holistic approach in designing a program to support participating undergraduate URM STEM students—hereafter referred to as STEM scholars. The program extends support with the following components: mandatory academic advisement; organized lectures, seminars, and informal meetings with STEM researchers and professionals; increased exposure to early research experiences and extended internships; formed learning communities of STEM student peers; robust one-on-one faculty mentoring, and career and peer-counseling (Diagram 1)

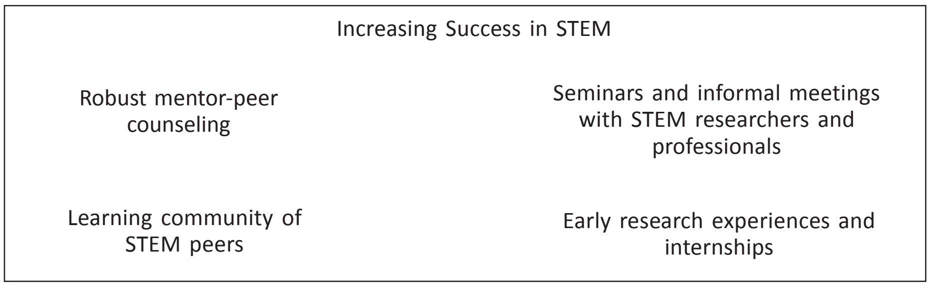

Figure 1: A model for supporting students for success in STEM

A more detailed plan for institution-wide activities in each of the four categories follows:

a) The program organized lectures, seminars, and informal meetings with STEM researchers and professionals, including women and URMs.

We periodically organized formal lectures and seminars by invited speakers, women and URM included, on various STEM topics. We also organized informal meetings with scientists and industry professionals with Q &A opportunities for the STEM scholars. We regularly invited City Tech alumni speakers holding jobs in industry or pursuing postgraduate studies in a STEM- related field. These forms of meetings between students, faculty, and invited scientists were very popular. We organized field trips to science exhibitions and tours at different off-campus locations, including the Museum of Natural History, the National Museum of Mathematics (MoMath), the Advanced Science Research Center at CUNY, the New York Genome Center, Google, the EPA, and the Federal Reserve Bank (NYC). STEM scholars overwhelmingly reported that the invited lectures were informative, and the field trips were educational.

b) The program increased exposure of STEM scholars to early research experiences and extended internships.

We utilized existing resources and organized hands-on workshops and seminars throughout the academic year for all STEM scholars in order to foster and maintain interest in STEM. One example of such activity is the Math Club, where students meet every week to discuss different math-related topics. Another example is the recently founded SIAM (Society of Industrial and Applied Mathematics) Student Chapter at the college, whose goal is to introduce and make accessible to undergraduates cutting edge research topics in applied mathematics and industry, while providing career guidance and helping STEM students connect with faculty in order to work on research projects. SIAM meets twice a month and provides the STEM scholars with a venue to share ideas that can help lead to faculty-guided research projects.

Based on a successful mentoring model (Ghosh-Dastidar & Liou-Mark, 2014), our program encourages all

STEM scholars to work on such research projects, whether through the college's Emerging Scholars Program, CUNY Research Scholars Program (CRSP), or various other undergraduate research opportunities available at the college, within the university, and at off-campus facilities. A biannual Research Mixer event organized by City Tech faculty provides students about various on-campus research and/or internship opportunities. Moreover, most of the baccalaureate programs in our institution, including Applied Mathematics, Biomedical Informatics, Applied Chemistry, and Applied Computational Physics, require completion of an extensive internship as part of their respective curricula, and we extended these internships to our STEM scholars. Many students from these baccalaureate programs have been active in presenting their research at regional and national conferences, and the STEM scholars were no exception. They were supported by various institutional structures such as the WAC (Writing Across the Curriculum) Center, which offers workshops on writing research proposals and abstracts, on proper citation and attribution, and on preparing poster presentations. The program has also worked on creating opportunities for multidisciplinary and multi-institutional research projects for teams of STEM scholars, an example of which is the joint undergraduate research collaboration between the college and the Chemical Engineering Department at Indian Institute of Technology (Kharagpur, India). Based on these concerted efforts, around 75% of the STEM scholars reported research and/or internship experiences during the program duration.

c) The program formed and fostered learning communities among STEM peers.

We organized multiple learning communities and created program-related structures to foster their success. Whenever possible we arranged for pairs of participating STEM scholars to collaborate on related research projects supervised by a faculty member. Furthermore, we had a solid academic support structure that principally relied on peer learning. Peer-led Team Learning (PLTL)—a student-centered model wherein participants actively learn in small groups facilitated by a student peer leader (Gosser et al, 2000)—is broadly utilized at our institution. A sizable portion of our mathematics classes feature PLTL supplemental workshops, which meet once a week for an hour of collaborative mathematics problem solving. Results have shown that the math courses with PLTL workshops have at least 15% higher pass rates, and at least 15% lower withdrawal rates (Liou-Mark et al, 2013). Results also showed the PLTL to be highly effective for first-year underrepresented minority STEM students (Liou-Mark et al, 2015; Liou-Mark et al, 2018). Among introductory biology students who opted not to enroll in the optional lab course, those who participated in PLTL averaged more than a letter grade higher than those who did not (Snyder et al, 2015). Other studies of the effect of PLTL have shown that non-PLTL population shows approximately 65.5% passing rate compared to approximately 81% for courses with PLTL workshops (Cracolice & Deming, 2005). In our case, many of the STEM scholars benefit from the PLTL support environment not only as participants in the peer-led groups, but also as peer leaders, who receive peer-leading training and facilitate learning in the peer-led communities.

d) The program offered a mandatory academic advising, robust one-on-one faculty mentoring, career and peer-counseling for STEM scholars.

All participating STEM scholars are required to meet with faculty mentor regularly and discuss academic progress and career development opportunities. Such mandatory one-on-one academic advisement is scheduled at least twice a year before the beginning of registration for classes for the following semester. Such advisement has been found to be particularly beneficial, as it helped student navigate the shortest path to graduation.

Additionally, we directed STEM scholars towards a wide range of career counseling and job-placement services. The Counseling Services Center offered help to students who were uncertain about their career choices. A number of online tools such as a Virtual Career Library and career assessment instruments including SIGI (a comprehensive, interactive, computer-assisted career guidance program) and the Strong Interest Inventory (an interest inventory used in career orientation) were made available to the STEM scholars as well. Regular peer gatherings offered participating STEM scholars space to discuss internship, research, application to graduate school, and other academic topics. STEM scholars were also required to open LinkedIn accounts, which has been shown to be an efficient way for alumni to stay in touch with one another and with the institution.

PRELIMINARY FINDINGS

We have the following reports available on the planned activities and outcomes:
1) The program recruited a high percentage of women and underrepresented minority students from local minority-serving high schools, as well as from undeclared and liberal arts majors with strong mathematics background who were interested in enrolling in the targeted science, technology, engineering, and mathematics majors. Table 1 shows the number of STEM scholars enrolled by semesters, percentage of women enrolled, and amount of scholarships given.

Semester	Fall 2015	Spring 2016	Fall 2016	Spring 2017	Fall 2017	Spring 2018	Fall 2018	Spring 2019
# of scholars	23	28	23	21	26	30	19	22
Amount Awarded	$54,800	$69,540	$56,153	$55,320	$55,575	$62,725	$36,350*	$51,527
% Women (all majors)	39% (9)	43% (12)	48% (11)	43% (9)	50% (13)	50% (15)	63% (12)	68% (15)
% Women (Applied Math & Computer Science majors)	25% (2/8)	23% (3/13)	33% (3/9)	30% (3/10)	38% (5/8)	23% (7/16)	54% (7/13)	54% (7/13)
% Women (Biomedical Informatics & Chemical Technology)	47% (7/15)	60% (9/15)	57% (8/14)	55% (6/11)	44% (8/18)	57% (8/14)	83% (5/6)	89% (8/9)

Table 1: Scholar Profile, Percent Women Recipients of Scholarships by Major

From 2015 to 2019, the percentage of women STEM scholars who received financial support in the form of scholarships increased by 29%—from 39% in the Fall semester of 2015 to 68% in the Spring semester of 2019 in all STEM majors; and from 25% in the Fall semester of 2015 to 54% in the Spring semester of 2019 for Applied Mathematics and Computer Science majors alone.

2) The program provided comprehensive support structures—financial support, academic advisement, academic support, and career counselling—at critical junctures.

* In Fall 2018 the students' unmet financial need decreased and thus STEM scholars were awarded a smaller amount in scholarships compared to previous semesters.

Semester	Fall 2015	Spring 2016	Fall 2016	Spring 2017	Fall 2017	Spring 2018	Fall 2018	Spring 2019
# of scholars	23	28	23	21	26	30	19	22
% Receiving Advisement	100%	96%	100%	100%	100%	100%	100%	100%

Table 2: Percent of Scholars Receiving Faculty Advisement

Nearly 100% of STEM scholars have consistently received academic advisement, and 100% of them met at least once per academic year with the program leaders for one-one-one mentoring related to academic progress, career counselling, graduate studies, and professional development.

3) The program organized lectures, seminars and informal meetings with STEM researchers and early exposure to research and internship opportunities.

There were multiple talks, informal meetings, museum visits, seminar and workshops consistently offered throughout 2015-2019. Nearly 100% of the STEM scholars attended at least one of these events per semester. About 75% of the STEM scholars were engaged in at least one research project throughout the program period, and 89% of them reported on being either a peer-leader or workshop participant. In addition, 21% of the STEM scholars have presented research posters at Women in Computing Conference. Data on other conference presentations are still pending.

4) The program facilitated forming STEM peer-communities and has made concerted efforts in strengthening them.

Over the reporting period, multiple pairs of STEM scholars were formed and organized to work on a research project with a faculty mentor. This data is still being processed.

Additionally, 90% of the STEM scholars reported to have opened a LinkedIn account in order to stay in touch with peers or follow scientists who had given presentations during the period.

5) The program retained and graduated STEM scholars at a faster rate and with higher GPA and lower total number of credits earned by graduation.

The program retained and graduated STEM scholars through strong mentorship and advisement for selection and registration for the optimal courses and number of credits. Participating STEM scholars earned on average 29-30 credits annually, which is higher than the average number of credits per semester earned by students in STEM majors. The average STEM scholars' cumulative GPA was also higher compared to the average cumulative GPA of students in STEM majors. Table 3 shows STEM scholars' mean cumulative GPA and mean number of credits earned during each semester of the program.

Semester	Fall 2015	Spring 2016	Fall 2016	Spring 2017	Fall 2017	Spring 2018	Fall 2018
Mean Cumulative GPA (Median)	3.46 (3.43)	3.53 (3.58)	3.50 (3.52)	3.52 (3.56) $\sigma = 0.31$	3.52 (3.54)	3.56 (3.55)	3.59 (3.59)
Mean Number of Credits Earned (Median)	15.65 (16)	13.86 (14)	14.04 (14)	15.71 (15)	14.19 (14)	15.00 (15)	15.42 (16)

Table 3: STEM Scholars' Cumulative GPA and Credits Earned per Semester

For comparison, full-time freshman in bachelor's programs at the same institution in AY 2014-15 earned on average 22.7 credits and only 23% of all students earned 30 or more credits. Full-time students in associate (two-year) degrees in the same institution in AY 2014-15 earned on average 19.4 credits and only 9% of all students earned 30 or more credits.

In addition, the average total number of credits earned by STEM scholars by graduation was also higher compared to the average total number of accumulated credits by graduation of students in STEM majors. Table 4 shows the average number of credits and GPA earned by STEM scholars at graduation.

Academic Year	Associate Degrees		Baccalaureate Degrees	
	Mean Number of Credits	Mean GPA	Mean Number of Credits	Mean GPA
AY 2015-16	81.5 (n=2)	3.375	124.8 (n=7)*	3.57
AY 2016-17	58 (n=1)	3.98	133.6 (n=15)*	3.46
AY 2017-18	80 (n=1)	3.17	125.5 (n=10)	3.61
AY 2018-19 (Fall only)	71 (n=1)	3.39	121 (n=4)*	3.71

Table 4: GPA and Credits Earned by Graduation

Overall, the STEM scholars from associate degree (two-year) programs earned on average 74 credits by graduation as compared to an average between 80 to 84 credits earned by an associate degree graduate with a STEM major. Similarly, the STEM scholars who graduated with baccalaureate degree earned on average 128 credits by graduation as compared to an average between 103 to 138 credits earned by a baccalaureate degree graduate with STEM major.

Eighty percent (80%) of the STEM scholars have either graduated or will be making satisfactory progress toward graduation by AY2019-20. As of Fall 2018, five students have earned associate degrees and 36 earned bachelor's degrees. This accounts for over 50% of the participants in the program who have graduated, 12 of whom with honors. On average, the STEM scholars are on track to graduate one semester earlier compared to other full-time students from the same majors who did not participate in the program. Overall, the STEM scholars who completed their degrees graduated with a decreased number of semesters of coursework.

6) The program has increased the number of STEM students transferring from a two-year program to a four-year program.

[*] Some scholars did not receive scholarships during their last semesters due to holding a part-time status

A total of 16 of the 82 participating STEM scholars have transferred from a two-year to a four-year degree in the five-year period. The total number of STEM scholars transfer students represents 20% of all STEM scholars, and an increase of the initial 11% of participating STEM students from a two-year degree in 2015. In summary, the program was successful in increasing student participation in STEM programs, especially women and underrepresented minority students; in increasing the number of STEM students transferring from a two-year program to a four-year degree programs; in providing comprehensive support structures such as financial support, academic advisement, academic support, and career counselling; in retaining and graduating women and underrepresented minority students in STEM; and in decreasing the number of years to graduation of STEM students who participated in the program.

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"THEY'RE ALL GOING TO HEAR YOU BEING SILLY": CHALLENGING DEFICIT VIEWS OF MATHEMATICS CLASSROOM PARTICIPATION

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This paper seeks to critically examine the mathematics classroom and illuminate modes of viewing the classroom by teachers and researchers that might constitute a deficit perspective. The focus of the study is a fourth-grade classroom in an urban charter school in a major US city on the North-eastern coast. The students in the class were engaged in computerized mathematical tasks designed by a team of mathematics educational researchers. The researchers' primary focus was on developing a constructivist understanding of students' learning of fractions; this paper presents the findings of a secondary investigation into perception of student participation through a critical analysis of the speech-based interactions of one student. The case serves to illustrate one instance of educators' deficit gaze towards mathematics students, proposing a re-imagining of this gaze.

WHAT DO WE SEE WHEN WE LOOK AT STUDENT PARTICIPATION IN THE MATHEMATICS CLASSROOM?

In recent decades, researchers in mathematics education have taken an interest in the construction and expression of identity in the mathematics classroom (Gutiérrez, 2013). Research into identity and mathematical practice has been undertaken from various perspectives. Boaler (2002) and Boaler and Greeno (2000) highlighted the relationship between teaching practices and the development of mathematical identities. Nasir, Hand, and Taylor (2008) reported on how students' performance on mathematical work in traditional and non-traditional contexts reflected how they saw and situated themselves differently in each setting. Esmonde and Langer-Osuna (2013) adopted a figured worlds lens (Holland, Lachicotte, Skinner, & Caine, 1998) to describe how students tend to cast themselves in different roles in different social realms, which in turn could serve as resources for students to empower themselves within formal mathematics schooling. In thinking about identity, the research cited here has focused on the relationship students have to being in the classroom, to other students, and to the practice of mathematics.

A significant portion of identity research has focused on the specific ways in which mathematical engagement produces and is produced by various social relationships (Gutiérrez, 2013; Langer-Osuna, 2018). The questions of researchers tend to emphasize identity as it applies to the accomplishment of mathematical work in the classroom or the ways in which extant social identities and narratives about social groups may realize or disrupt success in formal mathematics (Boaler & Greeno, 2002; Gutiérrez, 2013; Nasir & Shah, 2011). The breadth of such radical research has pushed the mathematics education community to contend with the ways in which identity and power are implicated in access to school mathematics; it has also inspired discussions on how disrupting the processes of school mathematics—from curriculum to pedagogy—might be essential to reimagining the classroom and creating an equitable learning environment within it (Darragh, 2016; Gholson & Wilkes, 2017; Gholson & Martin, 2019; Gutiérrez, 2013).

It is to this latter goal that I direct the study described in this paper. I am interested in thinking about how educators and researchers view students' activity and interactions in the mathematics classroom and how this gaze casts students in specific roles that influence the making of their mathematics identities. To this end, the paper takes an interest in all student activity, speech, and interaction, even that which may not explicitly be considered as being related to mathematics. In particular, I include data that some within the research community might characterize as "off-task" interactions—interactions that are not explicitly about the mathematical task students are expected to be engaged in—in enabling and dismantling participation and collaboration during mathematical activity (Langer-Osuna, 2018). It is important to note that the framework of the study reported here does not classify interactions as "on-task" or "off-task". Instead, it seeks to unpack the many ways in which classroom interactions might be coded by teachers and researchers, and the implicit expectations surrounding mathematical performance that such coding reveals.

The mathematics education researcher is well positioned to examine the participation of the student in the classroom as a means to understanding the expectations of the space. Compared to the teacher, the researcher is in a more privileged position to do the humanizing work of seeing the student as engaged in the social practice of classroom mathematics (Esmonde & Langer-Osuna, 2013) rather than as a student of mathematics assessed to be at some level of success. hooks (1994) describes the "dis-ease (irrespective of their politics) among professors when students want us to see them as whole human beings with complex lives and experiences" (p.15). One might argue that a similar "dis-ease" persists among educational researchers when asked to regard the subjects of their studies—both teachers and students alike—as more than teacher and student. Among mathematics education researchers the discomfort is amplified, as the community remains divided on whether mathematics and its teaching have a socio-political dimension at all. This disagreement and discomfort notwithstanding, I take the view put forth by Gutiérrez (2013): that a socio-political grounding in research is crucial to rethinking mathematics education research, and that such a grounding demands viewing the mathematics classroom space from the perspective of those subordinated by it.

THEORETICAL FRAMING

This paper adopts Gholson & Martin's (2019) conceptual lens on mathematics learning as a performance that requires students to negotiate race, class, and gender identities simultaneously. Through an analysis of the speech-based interactions of one student during mathematics class, I try to illuminate the implicit expectations surrounding participation and interaction within the classroom space. The unit of analysis for the paper is thus the mathematics classroom as a social and interactional space, where the doing of mathematics is constituted through interactions with mathematical tasks and materials; with other students; and with the teacher (Darragh, 2016; Esmonde & Langer-Osuna, 2013; Gholson & Martin, 2019; Gutiérrez, 2013).

As a first attempt at describing the mathematics classroom as a social space, the study illustrates and examines the interactions of one student, a black student. As such it is necessary to also frame the students' performance within the context of what it means to be black in the mathematics classroom, and what it means for the black student to be doing mathematics. Gholson & Martin's (2019) conceptual framework for studying mathematics learning as performance provides important context: Gholson & Martin justify their focus on blackness by describing the history of the mathematics classroom as an anti-black space in North America and the tendency of school administrators (as the primary actors on behalf of entrenched school systems) to police black bodies—specifically black female bodies—and regard them incapable of productive mathematical engagement. How blackness is taken up by the classroom space forms, therefore, some part of my theorization of the social space of the mathematics classroom.

Indeed, for sociolinguists studying Black English, research into language development in Black children is regarded as being worthy of its own subfield. Lisa Green, in her seminal work on the development of Englishes in black children, argues for the need to account for children's blackness in developing language teaching and assessment tools: how black children interpret and respond to teacher questions is often distinct from how non-black children typically might; when the black child is asked a what or what-and-how question, for instance, she is more likely to answer the "how" of it, ignoring the "what" of it (Green, 2010, p.6). As most educators and administrators work without such context, the responses and actions of the black children are disproportionately perceived to be incongruous and incorrect when compared with those of non-black children.

Other sociolinguistic research into Black bodies corroborates Green's (2010) arguments above and makes a case for educational research to discuss blackness when discussing black students' experience within the classroom space. Rickford & Rickford (2000), in their seminal work on African American Language "Spoken Soul: The Story of Black English", demonstrate how the language pervades American history, art, society, and popular culture "liv[ing] on authentically," (p. 3), in all spaces where life plays out in the United States, including schools. African Americans

> …still invoke Spoken Soul as we have or hundreds of years, to laugh or cry, to preach and praise, to shuck and jive, to sing, to rap, to style, to express our individual personas and ethnic identities ("'spress yo'self,!" as James Brown put it), to confide in and commiserate with friends, to chastise, to cuss, to act, to act the fool, to get by and get over, to pass secrets, to make jokes, to mock and mimic, to tell stories, to reflect and philosophize, to create authentic characters and voices in novels, poems, and plays, to survive in the streets, to relax at home and recreate in playgrounds, to render our deepest emotions and embody our vital core. (Rickford & Rickford, p. 4)

Indeed, soul inhabits Black spaces and the Black body so exhaustively that its invoking cannot be helped by those who speak it. Black performance is a tool for survival crucial to navigate the various spaces, including formal classroom environments, through which the Black body moves (Smitherman, 1999).

The sum of this research suggests that any examination of the social space of the North American classroom demands an account of blackness within that space: how do teachers and educators make available or inhibit access to mathematics learning because of how the formal classroom space takes up blackness? In other words, what is the dominant imagining of the mathematics classroom, how is this imagining raced, and how does this imagining cast students as learners?

DATA AND METHODOLOGY

This paper follows the engagement and interactions of a Black student named Olu, a nine-year-old in a fourth-grade mathematics classroom in an urban charter school in a North-eastern city in the United States. Olu uses he/him/his pronouns. The school is an urban charter elementary school located in a largely immigrant neighbourhood of the city. The majority of its students are from immigrant families of colour. Students in two of the school's fourth grade classrooms were participants in a three-month pilot study. They were engaged in pairs on computer-based tasks on fractions designed by the researchers for the pilot. The primary interest of the investigators was in developing a constructivist understanding of how young learners learn fractions through interactive fraction-related activity. Each class in the pilot study had between 24 and 28 students.

As the participants worked through computer-based tasks in pairs, the researchers recorded their laptop screens in order to keep track of choices made within the activity as well as their own speech and voice-based interactions with each other as they peddled through the tasks. The tasks were designed to be somewhat self-guided, with the teacher checking in on each pair every now and then during a lesson. Sometimes, the teacher would conclude the lesson with a whole-class debrief of some of the tasks.

A secondary analysis of data from the pilot revealed interesting aspects of students' participation in the classroom with the tasks. Students' speech consisted of conversations with partners about the task they were collaboratively engaged on; conversations about the task with non-partners; conversations with partners not directly related to the task both while performing task-related functions on the computer and while not; conversations with non-partners not directly related to the task both while performing task-related functions on the computer and while not; interactions with the whole class during teacher-led discussions; interactions with the teacher that were one-on-one, with a partner, or with non-partners.

In the two incidents analysed, Olu is working on a task with another student, Maggie. Maggie is a non-black student of colour for whom she/her/her pronouns are used. The episodes include instances of Olu interacting with the screen, with Maggie, with other students, and with the teacher, Anna. Anna is a white curriculum administrator who has been recruited to teach this class for the purposes of the pilot. She is, therefore, relatively new as a teacher to the students; still, she has been with the group for about 6 weeks at the time the episodes analysed were recorded. She has, at this point, developed a good, affectionate rapport with the students. It is also important to note that as an administrator who is stepping into the role of teacher for the express purpose of the pilot study, her interactions with the students is often influenced by the broader goal of ensuring the students are engaged with the mathematics through the particular tasks designed for the study by the research team.

Screen recording software and microphones were used to pick up both students' work on the computer-based tasks as well as student speech during each lesson. Based on screenshots of student work, we determined whether Olu's (and Maggie's) speech at a given point in time should be categorized as directly related to his mathematical activity or not. The transcripts described here are selected from portions that were determined to be directly unrelated to the mathematical tasks students were working on.

RESULTS AND ANALYSIS

In the analysis, I will describe instances of Olu's interactions from two different class sessions, interpreting them in terms of how his interaction is taken up (or not taken up) by Anna (the teacher) and by his peers (including Maggie, his partner). The first set of excerpts comes from a class in which Olu's partner, Maggie (who is also occasionally addressed as Magg), does not feel well for the duration of the lesson. Early into the class, Olu starts working through the tasks based on Anna's instructions. As he finishes his thinking on the first task, he relays his answer on the problem to Maggie:

Olu	:	Magg?
Maggie	:	<no response>
Olu	:	Magg!
Maggie	:	<no response>
Olu	:	The first answer is 18! Okay?
Maggie	:	<no response>
Olu	:	Are you okay? Are you okay?
Maggie	:	No.
Olu	:	You want me to do it by myself while you relax a little?

A few minutes later, as Anna stops to check in on the progress the pair are making, she notices that Maggie isn't participating in the tasks:

Anna	:	Maggie, are you helping?
Olu	:	No, she isn't feel good right now, I'm going to do the work for her.

Anna acknowledges Olu's response to her question, and moves on to work with other students. Several minutes after this exchange, Olu decides to check in on Maggie again:

Olu	:	Maggie, do you feel better now?
Maggie	:	(*inaudible*) A little.
Olu	:	Okay.

The design of the study required students to work collaboratively on the tasks, so that they discuss ideas and make decisions together as they work through prompts. This is a significant expectation of the pilot, one that Olu attempts to meet by repeatedly trying to get Maggie involves in their collaborative mathematical work. Olu becomes alert to her non-responsiveness. He starts checking in on her, repeatedly asking if she's okay, and then suggesting that she take care of herself while he does the work. Between these interactions Olu is engaged in doing the work, thinking aloud as he figures out a task, and even occasionally letting Maggie know what progress he's made.

Throughout this episode, the screen recordings of the app show that Olu is working through the mathematical questions posed within the task. He is using the functions available on the app to generate images and representations that he then uses to answer the questions. Sometimes, in the moments of silence between the three sets of interactions described above, he speaks the answers loud enough to the screen so that the microphones can pick it up; at other times he turns to Maggie and speaks the answers or "what he got" out loud; the rest of the time he records his answer on the worksheet provided to him by the teacher.

In thinking about this mathematics classroom as a social space, Olu's exchanges with Maggie and Anna suggests that the space is constructed to support students checking in and caring for each other; it suggests that the space supports a "doing" of mathematics that is simultaneous to these other types of interactions and cannot meaningfully be separated from them; it suggests that within the space, mathematical and non-mathematical activity are interwoven and need not be viewed as inhibiting each other in any way.

In the second instance presented for analysis, Olu continues to work by himself as Maggie, still feeling unwell, has left school early. Throughout this episode, Olu talks through the mathematical work, but much of this speech is interspersed with pronouncements about himself and with bursts of performance and singing. At nearly every stage of completing a task, Olu cries out the answer to no one in particular. "It's two!" or "It's four units, guys!" or "Another three, I think!" It remains unclear that anyone is listening as he shouts these answers out; yet for Olu the exclaiming seems like a way for him to validate and indeed affirm his work. In the same lesson, when Anna checks in and alerts Olu that he may have misread the directions on a task, Olu, upon realizing his error exclaims "I'm so stupid!" This is followed shortly by an exclamation of "I'm totally rocking this" after a different task. Olu's performance of mathematics is loud and excited; he is happy to have "got the answer," in some sense, and this might have to do with the value placed on the "right answer" in the classroom environment he finds himself in.

At some point in this episode, Olu starts to sing as he does his work. There is an entire four-minute stretch of data in which Olu sings uninterrupted, pausing only to shout out the answers he's found to an audience of researchers listening to the audio files several months later. His singing elicits two responses. The first is from another student in the class. The student calls out to Olu, saying, "You gotta start coming to chorus!" Olu pauses his singing to reply "I'm already in band!" That seems to be the entirety of the exchange, and Olu returns to his singing and task work. A few more minutes into this simultaneous engagement in singing and mathematics, we hear Olu counting numbers on the screen to the tune of the song he has been singing. Here, the singing appears to take precedence over the mathematics, with the latter being accommodated into the music that simply must be performed.

At this juncture, Anna arrives to check in on Olu's progress:

Anna	:	What are you doing?
Olu	:	Counting (*then resumes singing*)
Anna	:	If you're going to be silly on the microphone, then they're all going to Hear you being silly.
Olu:		I'm just singing.

At the end of this exchange, Anna leaves and Olu immediately resumes both singing and his mathematical work.

This excerpt illuminates both Anna's an Olu's different imaginings of the classroom. For Anna, counting must sound a certain way (and perhaps not like song) and "being silly" is not something that needs to be captured as data for "them". Perhaps for Anna, as it is with most teachers and educators, mathematics is done in isolation and cannot possibly be simultaneous to other activities like singing. As a teacher-administrator with a vested interest in making sure "they" (the researchers) have something meaningful to work with, Anna is also construing Olu's participation as non-mathematical, or, worse, anti-mathematical. In policing—even if gently and with affection—Olu's body and performance within the classroom, Anna is adopting a deficit view of his work; discounting the mathematics that he is clearly engaged in because of the way in which he is performing this mathematical engagement.

Because it *is* mathematical engagement, as Olu asserts: he's counting. He doesn't even view his own practice as "silly" the way Anna describes it; he is doing math. When Anna points to his "silliness," she is referring to his singing—something Olu realizes immediately, based on his response that he is "just singing". Even if for Olu his singing does not interfere with the other activities expected of him, Anna's gaze interprets singing and counting as activities intrinsically at odds with each other in the social space of her classroom. Olu continues to sing, to call out the answers, and to congratulate or berate the quality of his own work for the rest of the lesson. To Anna these interactions do not add up to mathematics; perhaps Olu does not see them as separate, and therefore is unable to tease them apart. .

DISCUSSION AND SIGNIFICANCE

Olu's being in the mathematics classroom summons several performances: of self-declared successful and unsuccessful mathematics doers, of the singer, of the caring friend, to name a few. His mathematical work continues unabated, and often his non-mathematical engagement gets fused with it. Indeed, it is the gaze of the teacher or the looming but invisible researcher that delineates the two as different types of engagement. What is produced is a sort of engagement often invalidated by the system, with teachers often questioning the value of the mathematical work done if it is performed in a manner different from what is prescribed by mathematicians and educators. Olu's interactions in these episodes offer important perspectives for mathematics educators and teachers to consider: why should singing and caring be thought of as somehow separate from and worse detrimental to the doing of mathematics? Why can't one count to a tune and why can't one percussively call out the answers to math questions without being framed as somehow disrupting the social practice of mathematics? Olu exemplifies what it means to be many things at once and reminds us that the student is so much more than just a student in the classroom; in fact, Olu reminds us that the mathematics classroom is and could be much more than a site at which specific forms of mathematical practice take place—he reminds us to consider that mathematical practice itself can be expansive enough to include many different types of social interactions.

Olu's story of affirmative expression of several identities in the mathematics classroom hold value for teachers and educational researchers alike. For teachers, it helps imagine the classroom as a far more active space in which mathematics can be accessed and executed in a multitude of ways. It may help teachers become more attentive to the myriad ways in which students demonstrate their mathematical abilities and help them also design classes to recruit students’ different identities to mathematical sense-making. For educational researchers, it provides an important lesson in what to attend to in the data. In ignoring non-mathematical data, we risk reducing the individual in the classroom to a student alone; by including such data we set ourselves up to better understand mathematics as a social activity. We are also able to see the classroom from the perspective of the student. I expect that students like Olu, who inevitably perform their various social identities in the elementary school classroom, eventually learn to “turn off” these identities at school or in the presence of teachers and re-learn how to perform mathematics for the black body, like Cameryn does in Gholson & Martin’s analysis (2019). Future research must consider the implications of this “learning how to be in school” for the personhood of the child as they enter and exit school spaces.

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FRAMEWORKS AND AFFORDANCES FOR INTERNATIONALLY DISTRIBUTED COLLABORATION (IDC) BETWEEN SCHOOL-AGED STME LEARNERS

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This paper engages multiple strands of interest, including sociocultural studies of STME, cognitive and affective studies of STME, and Language, Pedagogy, and Curriculum in STME. It originates in but does not limit itself to a US-based project for middle grade through college students in SubSahara, Finland, Brazil, Iran, India, and the US. The students collaborate on digital makerspace projects through video conference and through asynchronous virtual tools. This type of internationally distributed collaboration (IDC) with school age learners, while currently rare in educational settings, is likely to become more ubiquitous in coming years. The paper introduces the project as an exemplar of IDC involving school-age learners, and reviews two aspects of its research methodology.

INTRODUCTION

For the purposes of this paper, Internationally Distributed Collaboration, or IDC, refers to computer-supported collaborations that are both synchronously and asynchronously virtual. Scenarios of interest involve teams whose school-aged participants (or teachers) reside in different countries or cultures and who collaborate on specific science, mathematics, or technology education (STME) challenges or projects in the context of formal or informal educational settings. A multiyear research effort supported by the US National Science Foundation (NSF) serves as exemplar for a discussion on IDC more generally, and for the theoretical frameworks they entail and the affordances that they provide. The session will include results from that IDC, involving students in the US and counterparts in Brazil, Finland, Kenya, Namibia, and Mexico.

IDC in the Workplace Versus School Setting

IDC in the *workplace* is common. Cross-national workplace teams come in all varieties, and include members not only from different countries, but also different cultures, economic backgrounds, and generations. Contemporary video- and tele-conference technologies enable shared virtual presence for synchronous collaboration and communication in the workplace. Virtual presence enables participants to cross geographic, cultural, generational and other boundaries. Virtual teamwork across international boundaries is already a ubiquitous part of many work environments, and certainly integral to the work life of many, if not most, attendees of the biennial epiSTEME conference, for example.

Extensive IDC, however, remains relatively impractical in most current *educational or school settings.* The two most salient differences are age (young person versus adult) and setting (workplace versus school or learning environment). Logistical, privacy, and technological limitations impose practical impediments to widespread implementation. Additionally, complex IDC does not currently have the driving force in school practice that characterizes the need for adults to collaborate in the workplace so increasingly defined by globalization.

Yet each factor limiting such collaborations between young people in learning settings is manageable, and the expansion of social connections in global society will inexorably drive distributed teamwork in learning settings (Hamilton and Owens, 2018). One indicator that IDC ecosystems in STME settings can be realistically anticipated in the near-term future involves the agency funding the project appearing below. NSF recently supported a series of nine workshops to garner insights from prominent scholars in the areas of learning technologies and learning sciences. The agency sought to formulate long-term strategies for its research funding, and positioned IDC and other forms of collaborative "boundary-crossing" as one of a small number of areas to support for consideration for coming research funding (Hamilton, 2018).

International Community for Collaborative Content Creation (IC4)

The agency currently supports a prototype effort, called the International Community for Collaborative Content Creation (IC4) (Hamilton and Culp 2016). This multiyear research project has reached its midpoint as a network of school-based clubs in Kenya, Namibia, India, Brazil, Finland, and the US. (A small club in Iran does not affiliate with any school.) As an effort funded by the US government, about one-third to one-half of the participants participate in US clubs. NSF, along with various other organizations support clubs in the other five countries.

IC4 operates with the dual goals of offering rich learning experiences through its after-school club structure while carrying out design research emphasizing a blend of informal science and mathematics learning and makerspace collaboration across national, income, and cultural differences.

Makerspaces, as much or more than any current approaches in education, are often defined by physicality and by the opportunity they provide learners to manually experiment and construct artifacts that embody social cognition and obligate or spur intellectual growth (Peppler, Halverson, & Kafai, 2016). Among the most prominent makerspace domains are robotics, circuit board experiments, and 3D printing. A subset of the makerspace movement, though, involves digital activities. Among the best-known activities involves videomaking, games, coding, and commercial products such as Minecraft (Rippa and Secundo 2018).

This larger view of makerspaces encompasses the past decade's revolution in user-created digital media content. Because it takes place over internationally distributed virtual spaces, the IC4 project primarily (but not exclusively) falls into this subset of the makerspace movement. Figure 1 depicts the students in several countries sharing videos and other presentations that they have co-produced in what is called a global meetup – a synchronous videoconference.

The online global meetups of the type that Figure 1 depicts have emerged as a key component in building the IC4 community. The opportunity for visual, synchronous communication both motivated and built social trust among the participants, increasing the depth of interactions with time and experience. As more meetups have taken place, a shared understanding of the culture and behavior at meetups has emerged (Hamilton and Owens 2018). This includes a shared understanding of the roles within the meetups, such as a facilitator that guides the conversation and presenter(s) who share their paroject. With increased social trust built from meet-up experiences, comfort in interacting with one another across cultural and national boundaries has expanded. Makerspaces provide a rich context not only for innovative student learning experience, but also for research on learning and uncovering valuable insight for the effective design of future learning environments.

Figure 1: Students from elementary, middle, and university level settings in Finland, Kenya and the United States, in global meet-ups to discuss science and computing projects

Learning environments of the future will include routine and flexible, internet-mediated synchronous and asynchronous project collaboration (Dede 2010). Collaborations around making, or artifact creation in cross-cultural settings, obligate a variety of constructs and practices likely to alter and reshape future conceptions of learning. Among these constructs are three that IC4 emphasizes as an internationally distributed collaboration: social cognition, participatory teaching, and help-giving (Hamilton and Owens 2018, Hamilton and Kallunki in press). These types of phenomena are likely to emerge in dynamic and highly positive forms in the future.

RESEARCH METHOD

As a sponsored research project, IC4 yields multiples strands of data. Its flagship methodology involves quantitative ethnography (Shaffer 2017) and the epistemic network analysis (ENA) software tool. QE and ENA allow the research team to examine changes in the epistemic frames (Knight, Arastoopour, Shaffer, Shum & Littleton, 2014) of participants that relate to multiple constructs of interest. We examine approximately 20 constructs. Epistemic frames are somewhat analagous to the construct of funds of knowledge (Moje, Ciechanowski et al. 2004), i.e. the totality of unique experience, enculturation, beliefs, experiences, etc., that an individual brings into a social setting. Some of the most prominent of these include curiosity, self-awareness, feedback, content-focus, participatory teaching, knowledge acquisition, cross-cultural awareness, and social disposition.

ENA software models the structure of connections in data based on subject discourse patterns. ENA assumes it is possible to systematically use discourse to identify and code the constructs of interest, that conversational discourse structures data, and that construct connections within discourse are meaningful and important (Shaffer and Ruis 2017, Shaffer 2017, Siebert-Evenstone, Irgens et al. 2017). ENA models the connections between codes as construct proxies by quantifying their co-occurrence within conversations, producing a weighted network of co-occurrences, along with associated visualizations for each unit of analysis in the data. ENA yields a graphic depiction of the networks simultaneously, resulting in a set of networks that can be compared both visually and statistically. This method is treated in more detail elsewhere (e.g., Espino, Lee,

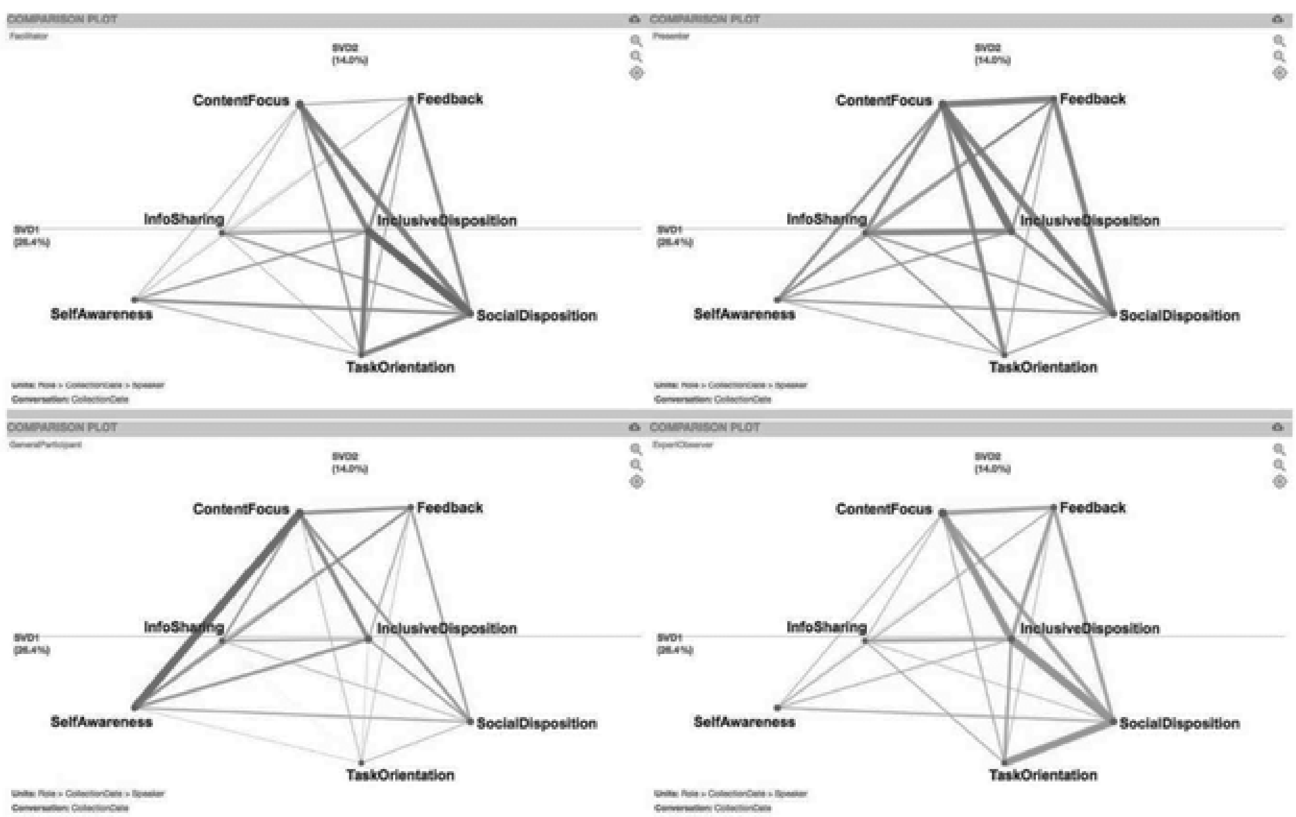

Figure 2: Discourse patterns demonstrated by different roles in IC4 online global meet-ups in 2017. The ENA models show how each role exhibited different patterns that are distinct from each other

Eagan & Hamilton, 2019), but Figures 2 and 3 furnish dual views of data. Figure 2 shows four ENA graphs representing teams from US and Kenyan sites from one of the IC4 global meetups in which students presented STME videos they prepared. These graphs document the emphases and connections that IDC students made in their conversation. The more saturated an edge between two nodes, the more frequently individuals in the group connected the associated constructs in the coded conversations. It can be taken as a given that groups will vary in their conversational emphases, though this type of analysis allows researchers to dissect conversations and visually depict with statistical frequency the connections that constitute the interactions.

Figure 3 provides data that more substantively illustrates the potential for visualization, beyond merely documenting differences between groups. It involves a case study involving one Kenyan participant's discourse patterns from over a one-year period. The student's contributions to collaborative conversations matured. The student evidences more integrated and expansive discourse patterns.

ENA thus depicts socio-affective, cultural, and academic variables – and, of crucial importance, the connections between them – that constitute epistemic frames of individuals and groups. Because they are sensitive to changes that discourse patterns reflect, they have proven valuable in assessing the nature and size of effects of IDC with school-age children.

Figure 3: ENA models depict discourse pattern changes by one Kenyan student in her interactions with peers in Finland and United States

ENA's underlying principle that discourse reflects the enculturation and cross-enculturation processes of internationally distributed collaboration with school-aged learners is complemented in IC4's use of cultural-historical activity theory (CHAT) (Greeno 2016) as another guiding framework for articulating how IDC for school-aged learners can function.

A common premise of the learning sciences is that activity mediates learning. Rather than preceding or preparing for activity, in other words, learning is embedded in activity systems. This is a key tenet of CHAT. The various constructs of actors, rules and norms, instruments, community, and outcomes form the activity systems that mediate learning (Greeno 2016).

Cross-Cultural Significance

More importantly, treating IDC through a lens that focuses on cross-cultural, cross-national shared activity in a virtual space, in pursuit of outcomes (such as STEM challenges or other digital artifacts) changes terms by which school-age learners form perceptions of self and others in parts of the world or in cultures that are remote to them. The virtual collaboration space, especially in synchronous video settings, enables visual communication with peers in other countries and cultures to take place from the familiarity of a student's own culture and context (Hamilton 2018). This neutralizes uncertainty, anxiety, or mistrust about those who live elsewhere. It does so by hybridizing physical presence - where the student is enculturated - with virtual presence in a collaborator's country and culture.

This phenomenon is familiar to adults accustomed to international virtual collaborations. For young learners, though, IDC provides opportunity to form understandings of the world by engaging those in other countries and cultures in an anxiety-neutral manner. In a world where strife and mistrust germinate because of geographical differences, there is opportunity to invent fresh ways for school-age learners to understand those who do not live near them nor like them. This compelling dynamic applies not only to geographic boundary-crossing, but to cultural boundary-crossing that can occur within a country, a region, or even within a city (Hamilton 2018). Displacing geographic or tribal perceptions imposed on a learner by parent or their immediate social system with productive collaboration as the primary basis for understanding those in other parts of the world may be an even more important contribution than purely advancing STME competences.

Forthcoming Directions

A recent "Rapid Community Report" (Hamilton & Espino, 2019) published by the Center for Innovative Research in Cyberlearning (CIRCL) defined several constructs foundational to IDC, including boundary-

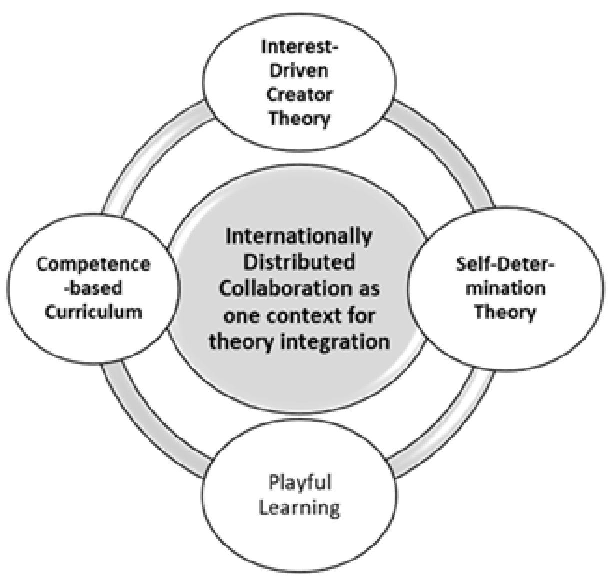

Figure 4: Research in Internationally Distributed Collaboration (IDC) can serve as a venue for synthesis and integration of important and emerging theoretical frameworks relevant to future education practice

crossing, virtual presence, interactional bandwidth, and social trust. Each of these play a critical and multi-level role in future IDC research. The Rapid Community Report also discusses the relationship between a) principles of cultural-historical activity theory reviewed in this paper; b) the emerging curriculum paradigm of interest-driven creator theory (another IDC acronym!) gaining traction as a coordinated focus of Asian researchers to reshape dominant test-driven policy patterns in their countries (Chan et al., 2018); and c) self-determination theory (Deci & Ryan, 2011) as a framework for understanding how IDC can simultaneously nurture three “primitives” of healthful personality integration, including relatedness, autonomy, and competence.

These each add definition and context to future research in IDC. Three other areas merit note in building a strong theory base for IDC research. Playful learning (Kangas & Ruokamo, 2012; Nousiainen, Kangas, Rikala, & Vesisenaho, 2018), emerging from Finnish educational research, appears to complement interest-driven creator theory from Asian education research. The international trend towards competence-based curriculum (e.g., Marope, Griffin, & Gallagher, 2017) surprisingly resonates strongly with interest-driven creator theory and playful learning in its emphasis on how to transition knowledge to effective functioning. The notion of a knowledge economy or a knowledge society increasingly appears obsolete or inadequate relative to the notion of competence across multiple domains as a step beyond knowledge formation. Figure 4 depicts the potential of internationally distributed collaboration (IDC, spelled out here to distinguish from interest-driven creator theory) between school-age learners as a rich venue for synthesis and integration of these theoretical frameworks. Such synthesis and integration in multiple venues will help to structure next generation and mid-century pedagogies

Finally, the fields of intercultural adaptivity or intercultural competence have garnered extensive attention and instrumentation in recent years. This literature, however, almost exclusively involves some variation of corporate, adult, or college populations. Similarly, it involves individuals who physically locate, permanently or temporarily, in cultures other than their culture of origin, or else are interacting with those from other cultures who now reside or work alongside them. Initial work in the area of intercultural competence formation among precollege adolescents, still in their earliest years of identity formation, has been undertaken by Schwarzenthal, Juang, Schachner, van de Vijver, & Handrick,(2017). One limitation attendant to surveys that track cross-cultural competence development formation is the suggestive nature of questions. Individuals may feel that parochial attitudes they hold do not align with expected normative responses. For this reason, one valuable direction for instrumentation for precollege intercultural competence assessment will be to develop survey questions that are embedded in other questions and in a way that minimizes implicit suggestions or priming of normative responses.

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STUDENTS' ENGAGEMENT WITH A CHAPTER ON 'FOOD PRESERVATION'

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The present study is part of a longitudinal project titled School Science Research and Development- Participatory Action Research. The study aimed to understand grade 5 students' ideas and experiences in relation to food preservation. In 6 sessions of regular school time, we found that a game, an activity and a worksheet on the topic made it possible for students to bring their daily experiences into the classroom. The discussions brought to the surface some misconceptions of students and also highlighted the language difficulties that students face with technical terms. The students' responses on the sub-topics showed a high level of student engagement and awareness of the ill-effects of food preservatives on health.

INTRODUCTION

The Indian school education system has undergone a major overhaul with emphasis on child-centred teaching-learning process. The National Curriculum Framework (NCF, 2005) recommends that "teaching of science should enable children to examine and analyze everyday experiences"(page ix). With reference to everyday experiences 'food and nutrition' is certainly a suitable theme for classroom science considering that natural, social, cultural and environmental aspects are associated with it.

Food and nutrition education is at the intersection of different fields of scientific and traditional knowledge and includes life experiences, cultural knowledge and practical experiences according to Rangel, Nunn, Dysarz, Silva & Fonseca, (2014), with reference to Brazilian schools. In the Indian context, very little scientific research or training programmes are conducted in the context of public health and nutrition (Khandelwal & Kurpad, 2014) which could contribute to the malnutrition and poor health of Indian adults and children. While there are larger social dimensions to the existence of malnutrition in Indian society (Sahu et al., 2015), nutrition education is important in the school setting. Studies in nutrition education discuss the need to design educational strategies considering students' prior knowledge, abilities and cultural relevance (Pérez-Rodrigo & Aranceta, 2003). Additionally, educational strategies should be engaging, creative and inexpensive. Implementing such strategies requires time as well as sustained interaction. According to Dixey et al.,(1999) school-based nutrition education should go beyond providing information to developing skills in the areas of food preparation, preservation and storage.

Textbooks at the elementary school level provide scope for including a wide range of topics related to food e.g., 'Food for all', 'Constituents of Food' and 'Methods of Preserving Food' (Grade 5, EVS textbook, Maharashtra State Board). The focus of this paper is on 'Methods of Preserving Food', as this topic emphasises both the science and the technology involved in food preservation. It also opens up possibilities for engaging students in discussions of local practices and diverse methods of food preservation.

We are a part of a Participatory Action Research project (PAR) in a low-income, Marathi medium school near our centre. In PAR, the focus is on the development of communities rather than the academic interest of the researchers (Cohen, Manion & Morrison, 2011). The current project is a longitudinal study with the objectives of improving the quality of science and environmental science (EVS) education in a nearby school and preparing of instructional material that can be shared with teachers. This project has already completed four years of collaboration between members of our centre and teachers of grades 3, 4, 5 and 6 while following one batch of students from grade 3 onwards. Some details of the objectives, experiences and learning of the first two years of the project have been reported earlier (Deshmukh, Bhide, Sonawane, Chunawala, & Ramdas, 2018).

OBJECTIVES OF THE PRESENT STUDY

This study focused on grade 5 students' knowledge and ideas informed by their experiences of the topic 'food preservation' and their attempts at making connections with food preservation methods and the related terminologies introduced in school.

METHODOLOGY

As part of the PAR project, we interact with the school teachers on a regular basis and help plan out the sequence of activities to be carried out in completing the topics in the textbook of Environmental studies. The project members of our centre develop these sequences and share the details with the teacher for her inputs. Typically, we get about a week (5 days) to complete a topic. The topic "Methods of Preserving Food" covered sub-topics which included need for storage of food, food spoilage and micro-organisms, and methods of food preservation (drying, cooling, boiling, placing in airtight cans, and others). Other than these topics mentioned in the textbook, we decided on 1) a game of arranging picture cards consisting of food items, 2) classroom interaction (based on concepts in the textbook) 3) activity of exploring empty food packets and finally, 4) a worksheet on methods and forms of preserving certain foods. For the game and the task on exploring empty food packets, students worked in groups. Worksheets were solved in teams of two students each.

Research Design

The study was planned as an exploratory research with a focus on gaining insights about students' ideas about the topic as well as connections of the topic to their daily experiences.

Participants

The study was carried out on the same class of grade 5 students who are a part of the PAR project. There were totally 70 students (30 girls, 40 boys) in this classroom, who had varied socio-economic and cultural backgrounds. The school overall caters to the lower socio-economic classes. Although the project is of participatory action research, when we conducted the current study, the teacher was unavailable due to some personal circumstances. Hence, one of the authors designed the activities and also taught in the classroom while the other author observed and took detailed notes of the classroom sessions.

INTERVENTION

To elicit students' ideas on shelf life of foods, the lesson began with a game (Day 1) in which students were required to arrange picture cards of 5 food items in increasing order of shelf life, i.e., in the order of food item getting spoilt first to food item staying fresh for the longest duration. The picture cards were of banana, milk, *chapati*, garlic and turmeric. For milk and turmeric, pictures of the packets containing the respective food were depicted to avoid any confusion. Students were divided into groups of 6 each. The question asked was; *if all of these items are kept at room temperature at the same time, in what order would they spoil?* Students were asked to provide reasons for the sequencing of their picture cards.

On days 2 and 3, students were engaged in classroom interaction about the concepts in the chapter as mentioned in 'Methodology'. On day 4, students were given empty packets of food items to engage with information on expiry date or 'best before' date and instructions on storage. On day 5, students were provided with a worksheet. Worksheets can be used as a mode to construct knowledge (Che-Di Lee, 2014), can support students' thought (Reid, 1984) and can be used by teachers to understand students' previous knowledge (Krombab & Harms, 2008). Through a worksheet, we can also involve every child in the learning-teaching process and can identify and address student misconceptions and facilitate learning for understanding (Griffin & Symington, 1997). The objective of the current worksheet was to understand students' learning and knowledge on food preservation and appropriate use of terms/diagrams to depict the same. The worksheet consisted of two questions. The first question required the students to suggest *ways* in which foods like mango, coconut, *amla* (Indian gooseberry), milk, and fish could be preserved and the *forms* in which they could be preserved. Students also could 'draw' the process or the product. In the second question, students were asked to write their favourite preserved food and its benefits, disadvantages and healthy alternatives for the same.

DATA COLLECTION AND ANALYSIS

The outcome of the game on picture-card arrangement was documented in the form of photographs. Worksheets solved by students and observation logs of classroom interactions served as data sources. Data was analysed qualitatively, wherein we have identified themes from students' responses and then analysed them.

The game (Day1)

The game was aimed at engaging the students and giving them some insight into what they would learn in the next sessions. Students worked in groups, discussed and collaborated on the appropriate arrangement of the picture cards of food items. A representative response from a group is shown in Figure 1.

Figure 1: Representative arrangement of picture cards depicting various food items.

The graph (Figure 2) indicates responses from various groups on the positioning of the food items. According to the graph, most groups indicated banana at the 1st position, suggesting that it can spoil first among the given items.

From Figure 2, it can be seen that most of the students reported the shortest shelf life for milk and banana. In the next position, again, milk, banana or chapati were mentioned. However, since more students stated that banana would spoil before milk, we probed this response. Students argued that "*the banana has already developed blackish spots, hence would spoil even before milk*". Their reasoning could be attributed to the fact that the banana in the picture card was a ripe one. For this game, it would be worth looking at students' responses to a picture card with a fresh and completely yellow banana. The longest shelf life was mentioned by students for turmeric, garlic and *chapati*. Picture cards of turmeric and garlic remained mostly at the last place indicating that students did understand that these items have a longer shelf life. These picture cards can be used as a resource for engaging students before discussions on topics related to food preservation.

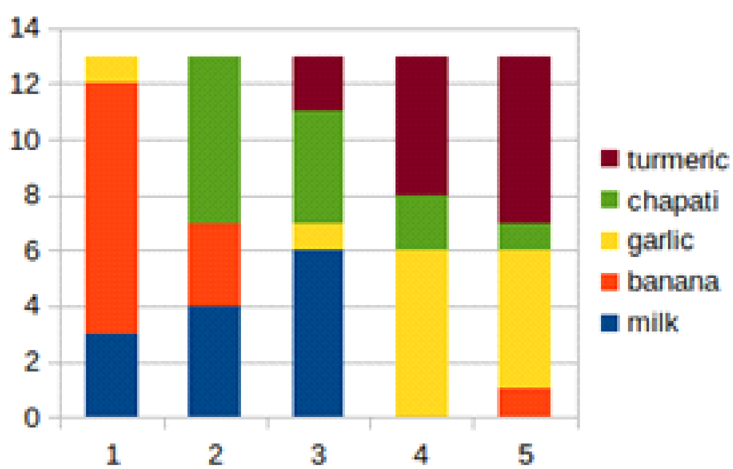

Figure 2: Graph representing students' responses in arranging picture cards. X-axis: position of food card with reference to their shelf life, indicating least shelf life to longest shelf life, Y-axis: Number of responses for that position.

One of the students mentioned (and other students agreed) that turmeric is *Ayurvedic*, hence, doesn't spoil easily and is thus at the last position. Another student added that 'being *Ayurvedic*' is the reason why turmeric is applied to wounds. *Ayurveda* is an alternative medicine system of natural healing with historical roots in

India. It appears from students' responses that they have tried to establish a connection of food spoilage with *Ayurveda*, indicating the false generalisation that if anything is used in *Ayurveda*, in this case, turmeric, it will have a longer shelf-life. Students may not be aware of the fact that milk, too, has a place in *Ayurveda* but spoils quickly. Thus, following the constructivist approach, presenting students with examples of foods used in Ayurveda but having a shorter shelf-life would help them understand that any food item with *Ayurvedic* properties need not necessarily have a longer shelf-life.

Interactions on 'preservatives' (Day 2 & 3)

In our interactions with students we found that they were unaware of the word used in the textbook for 'preservatives'. The word in Marathi for preservative (परिरक्षक) is highly technical and it is not surprising that students were unaware of this word. This word is unfamiliar to most adults too. When we discussed this word we found that students were confused between 'preservatives' and 'preserved foods'. Since one of our aims in the SSRD-PAR project is to focus on language, we would like to engage students with etymology of certain technical terms. Thus, introducing the term परिरक्षक = परि (around) + रक्षक (protector) could possibly enable a better understanding of the term.

Students were however able to tell about the harmful effects of preserved food such as "*too much oil may lead to throat infection (pickle)", "high blood pressure", "high sugar (diabetes)", "stomach infection*". These responses indicate students' awareness of disadvantages of consuming preserved food items. Further, to probe students' knowledge on the advantages of making preserved foods at home, we considered the example of *papads* (poppadoms). It was apparent that the practise of making *papads* was common in many students' families. This led to an animated discussion about the advantages of making *papads*. The responses received from students were: "*we save money by making papads at home," "we can make papads of various sizes and composition as desired," "can regulate the nutrients," "can be sure of hygiene."* Surprisingly, students did not, on their own, mention that we could also sell papads and make money. This is despite the fact that *papad*-making is a thriving cottage industry in India.

Engaging with food packets (Day 4)

Since empty food packets are rich in information regarding ingredients, nutrients, storage and packaging conditions, we thought that these packets are good resources to engage students in discussion about nutrition, storage and shelf life. Each group of 5-6 students was given an empty food packet and was asked to observe the packets carefully. The students were asked to mention all the details they could find on the food packets.

Not all food packets had an expiry date, instead, some had a date of packaging and a "Best Before" date. Most students struggled to read and understand the information in English and also due to the small font of the details on the food packet. Also, deducing the expiry date from packaging date and 'best before' date was challenging, as this required reading the dates in English and counting. However, a few months after this intervention, it was heartening to see that students mentioned the concept of 'expiry date' in at least 3-4 interactions, on related sessions on medicines and food. It is apparent that students had possibly picked up the skill to read a label after this activity or were aware of the need to do so.

Worksheet (Day 5)

This section presents students responses to the worksheet which required them to respond in writing or through drawings about methods of preserving foods. Students gave diverse examples of preservation of the food items provided on the worksheet. They drew or wrote about various techniques like drying, freezing, use of preservatives like oil, sugar, salt, etc. for preserving these foods (Table 1). The responses indicate students' experience from observation/participation in preserving foods. However, certain responses like '*keeping in dried grass/hay*' for mango is actually a technique to ripen mangoes in a short duration of time. Similarly, keeping foods in vessels is a way to store and not preserve a food item. Such responses indicate the need to clarify the difference between 'preservation' and 'ripening'. Interestingly, students also wrote that '*coconut can be left on the tree*' or '*fish can be left in water'*, so that these foods follow their natural course, which, again, are not methods of preservation, but are relevant methods of preventing wastage of food. It was heartening to see that students have such broad conceptions that involve ideas of delaying harvesting, fishing only when needed and converting into other food products like extracting oil.

Theme/ Categories	**Food Item (Mango, Coconut, *Amla*, Milk, Fish)**
Method of preservation	Drying, [(drew Sun, coconut, amla], Applying salt (fish)
Make a food item	*Barfi* (coconut sweet), *Paneer* (cottage cheese from milk)
Natural course	Let it be on tree (coconut), Let it be in water (fish)
Refrigeration (short-term)	Keeping in fridge (milk)
Storage, not preservation	Keep in vessel (mango), Keep in bag (coconut)

Table 1. Students' representative responses to the question on methods and forms of preserving various foods. Words in parentheses indicate the foods for which the particular response was given.

In the next part of the worksheet, students were asked "What is your favourite preserved food? What are the advantages of that food? What are the risks of eating that food? Can you suggest healthy alternatives for such foods?" Table 2 summarises the students' representative responses. Students' responses indicate that they were able to suggest alternative foods that could be made at home using similar source materials, compared to the commercially available foods that contain a large amount of salt, sugar or oil as preservatives. From the worksheets as well as classroom discussions, it was apparent that students were aware of the ill-effects of excess oil, sugar and salt on health. They were also aware of regulating the amount of preservatives while preparing side dishes such as jam and sauce at home.

Preserved food	**Advantages**	**Disadvantages**	**Alternatives to preserved food**
Pickle	Can eat during meals (as a side dish)	Can cause coughing (due to excess oil)	Tomato, Mango (can make side dish/salad using tomato and mango)
Jam	It stays longer	Too much sugar	Fruit (homemade jam using fruits)
Sauce (ketchup)	Longer shelf life	Salt in blood (sic)	Add less salt while making tomato sauce at home

Table 2. Representative responses by students to the question on benefits, disadvantages and alternatives for preserved foods

The worksheet, thus provided an opportunity to discuss, think critically, draw and write about students' understanding of 'methods of food preservation'. This worksheet can be modified to include other items within students' experiences, and can be a resource material for teachers to initiate discussions around the topic 'Methods of Preserving Food'. Additionally, it will be helpful if students can collate information on various foods preserved in their family/community traditionally and the different ways of preserving foods in communities. This can be done by recording oral history of the various food preservation techniques followed for different foods, from elders in the community.

CONCLUSIONS

The study indicates that students were able to connect experience from their daily lives with the themes in the chapter and could also acknowledge the social aspects of food preservation methods. They were aware of the health risks associated with food preservation. The various tools of teaching, namely picture cards and empty food packets aroused students' curiosity with respect to shelf-life of foods, and storage and packaging conditions. These tools including the worksheet are inexpensive educational strategies that involve students in activities and discussions. Thus, there is a wide scope for making 'Food' as a part of curriculum throughout schooling, especially with respect to 'Methods of Preservation', as it opens up new avenues for students to explore various areas of learning associated with 'Food'. It is surprising that there is no topic related to 'Food' in both the Maharashtra State Board and the NCERT curriculum after grade 7. We would like to urge the inclusion of various aspects of 'Food' under the sub-themes such as design and eco-friendly practices in packaging and disposal, 'food poisoning' as a major health issue and its prevention in higher classes.

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WEM: AN AV-TOOL FOR MOTIVATION IN ENGINEERING MATHEMATICS

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The study aims to present the making of WEM (Why Engineering Mathematics?), an audio-visual (AV) aid developed to motivate first year engineering students towards learning mathematics. The paper also investigates the effects of WEM on undergraduate engineering students. Pre-Survey and post-Survey tests were taken on the single group to check the effectiveness of the tool. The results indicated that WEM promotes students' motivation and positive approach towards learning engineering mathematics.

INTRODUCTION

Motivation in education plays a very important role in learning. One of the most difficult aspects of being a teacher is how to motivate students to learn your subject, especially when the subject is mathematics. Students who are not motivated will not learn efficiently. Either they will not retain information or will not participate in life-long learning or will become disruptive. For effective teaching, teachers must take students' learning motivation into consideration, because pupils learn only if they want to learn (Fairbrother, 2000). Students' motivations tend to focus on learning goals such as understanding and comprehensive knowledge of mathematical concepts (Ames & Archer, 1988; Dweck, 1986). How to encourage students' motivation and to understand their learning abilities in mathematics is very important. Some authors such as Klingbeil, Mercer, Rattan, Raymer, and Reynolds (2004), Middleton and Spanias (1999), and Zakaria and Nordin (2008) have addressed the issue of motivation in mathematics learning but as compared to other subjects, for mathematics education, motivation and the difficulty of finding reliable and valid methods for motivating learners is not discussed much. In this paper, the author presents WEM as one of the valid methods for motivating learners.

There are several reasons for students being unmotivated towards engineering mathematics learning. A survey was conducted at the beginning of the first semester of engineering. Around 240 first year engineering students of K. J. Somaiya College of Engineering, (KJSCE) Mumbai, were asked to answer some survey questions related to mathematics and their approach towards mathematics. All students, who participated in survey, were with above average academic score (Maharashtra Common Entrance Test (MH-CET) score more than 100 out of 200 marks). Findings are really surprising and some of them shocking!!

- More than 70% of students have learnt mathematics without relating it to real life.
- Around 60% students are unable to list a single application of mathematics in their day to day life or in any other field.
- Majority of students admitted that they don't know why they are being taught mathematics as they

have not yet applied any of maths concepts in their life!!

- Few students agreed and commented, “Of course math is useful but they don’t know where!”

Some interesting comments were, “Up to topics such as profit- loss, fractions etc. was useful but why this integration, differentiations, matrices etc. are been taught? It is completely abstract and useless!,” “I don’t understand why mathematics is included in engineering curriculum? Till now I have not used my 11-12th Grade mathematics anywhere,” “Math is only there to score well and raise pointer, nothing else.” Some students fear mathematics and are less motivated towards mathematics learning. Some of them commented, “I cannot see any physical relevance of Math! That’s why I don’t understand it at all.” The survey results clearly indicate the approach of teaching mathematics in their school level needs improvement. Engineering students remain demotivated towards their maths learning because they are not communicated about

- Usefulness of mathematics in core engineering subjects.
- Real life applications of mathematics.
- Requirement of mathematics in higher studies & research.

One approach to overcome this challenge is to provide the insight of applications of mathematics in day to day life, in student’s area of interest and their main domain of work.

To keep students motivated and to raise their inclination towards engineering mathematics, the author developed an audio visual aid “WEM: Why Engineering Mathematics?”

DEVELOPMENT OF ‘WEM’

WEM is an audio-visual aid, which contains interviews of selected teachers teaching core engineering courses (based on experience of subjects taught related to mathematical background), the Principal, Deans, alumni (working in fields having more applications of mathematics) and selected students from higher grades who can relate core subjects with mathematics.

Figure 1: Clips of WEM: Interview with the principal, faculty, alumni and students

These people were asked to share their experiences about applications of Applied Mathematics-I in core engineering subjects and day-to-day life. During interviews, they also talked about why students should learn Engineering Mathematics or why Mathematics is in Engineering Curriculum. They were also asked about relevance of mathematics in other subjects, higher studies and research. WEM was exclusively created for first year engineering students. The interviews were recorded in the form of audio-visuals. Total three videos were developed to address branch-specific requirement of different branches of engineering. For eg., the video developed for computer and IT engineering students, contained applications related to areas like cryptography, data analysis etc.

This paper is discussed with the data related to department of computer engineering and department of Information Technology. The video can be accessed on the following link with prior permission.
https://drive.google.com/file/d/1KmSQrHZG-erTonolg7_y_iTIclPAtjY0/view?usp=sharing

The interviews were conducted by students of “Emfinity”, the official Math club of KJSCE. The video was shot and edited by students of “Team Shutterbug”, the official photography team of KJSCE.

The objectives for developing WEM were
- To motivate students towards learning engineering mathematics
- To increase awareness about mathematics and its requirement in curriculum of engineering
- To inform students about applications of mathematics in day to day life
- To connect mathematics with other subjects
- To inspire students to find more applications of mathematics

Some of the questions asked to interviewees were:
- What is the importance of mathematics in engineering curriculum?
- How does mathematics relate to other subjects?
- How can we use mathematics in our daily life?

DEMONSTRATION OF ‘WEM’

The WEM was shown to every student of first year engineering at KJSCE in the beginning of the semester. Before showing the video, data was collected through questionnaire about their knowledge and approach towards mathematics learning. Total 219 students from Computer engineering and Information Technology department participated in both pre and post invention survey. The students were called out of their regular class and were asked to sit in well-equipped seminar hall. Students got excited with the theatre kind of environment and felt like they were going for a movie with their friends. The excitement reached its peak when they realised that the movie which they are about to see is the complete effort of their own seniors and teachers of the college. This was the first time in their life when students were asked to see movie in their maths lecture!!

Students felt that every question which was posed in the movie was straight from their heart and was never answered before in any of their maths classes before this. They were fascinated by witnessing many other students and teachers, including principal of the college, talking about mathematics. Before this, they had heard only maths faculty talking about mathematics. Students realised that mathematics is not just required to score marks in exams but it has relevance for other subjects in higher studies, research and also applications in day to day life. They could now see mathematics beyond the curriculum and subject.

Figure 2: Demonstration of WEM

STUDENTS SELF-ASSESSMENT ON 'WEM'

Students were asked to self-evaluate themselves through the questionnaire. The same questionnaire was floated to students before and after showing WEM. The following figures indicate the responses obtained on different items of the questionnaire.

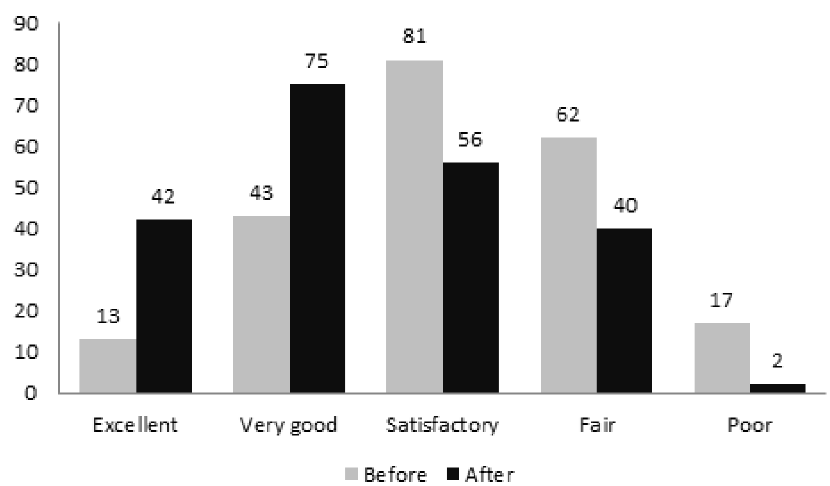

Figure 3: Rate yourself on the basis of your knowledge of application of mathematics in day to day life

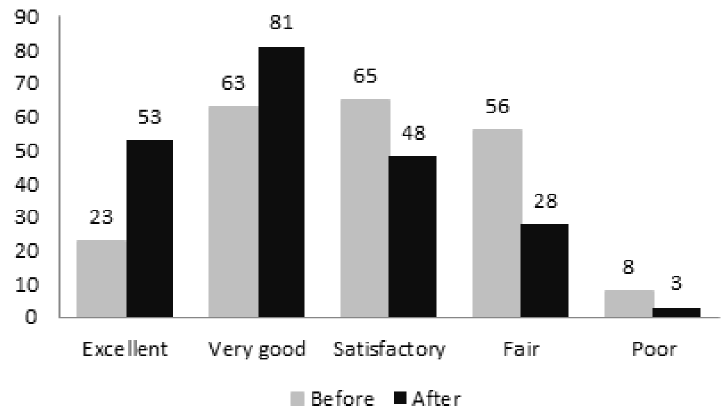

Figure 4: Rate yourself on the basis of your knowledge about connection of mathematics with other subjects

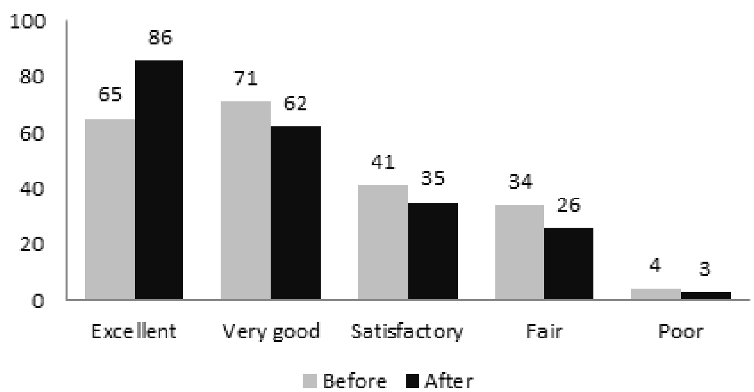

Figure 5: Rate yourself on the basis of your interest in learning mathematics

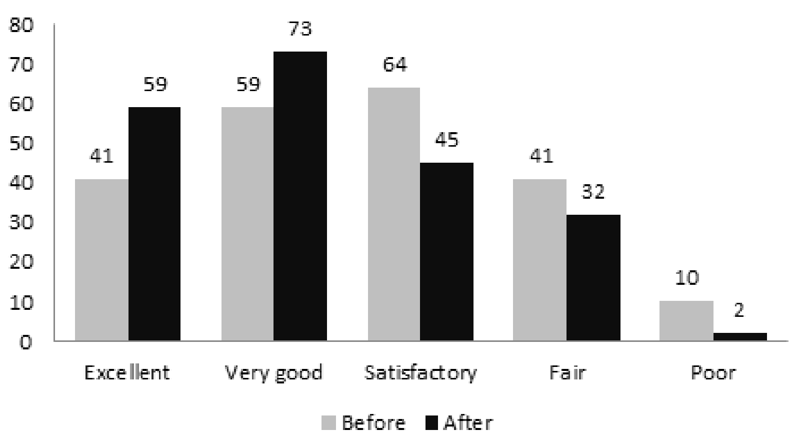

Figure 6: Rate yourself on the basis of your interest to find applications of mathematics

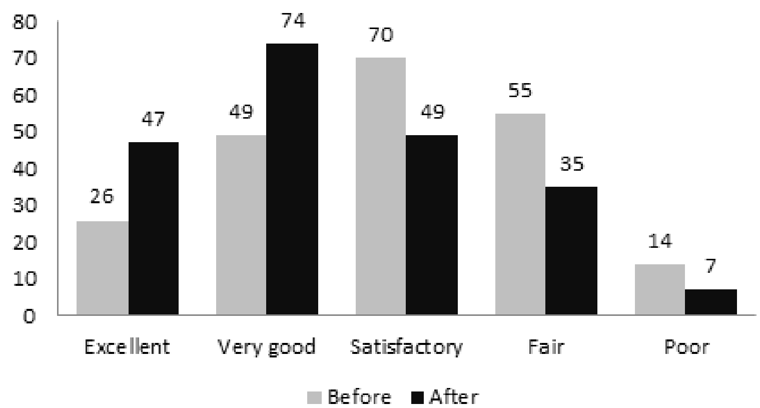

Figure 7: Rate yourself on the basis of use of internet in finding applications of mathematics

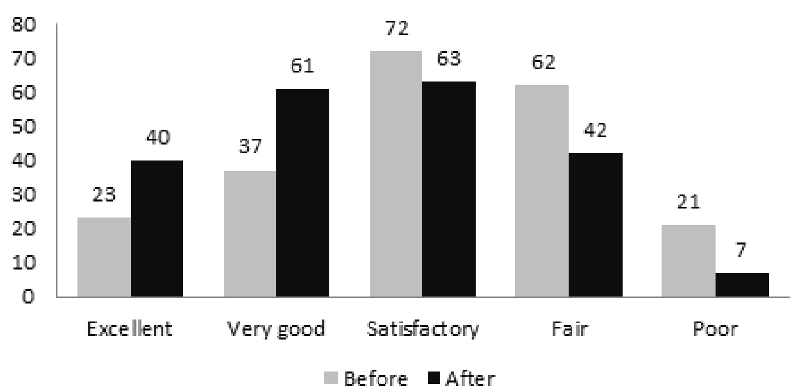

Figure 8: Rate yourself on the basis of your interaction with other world about applications of mathematics

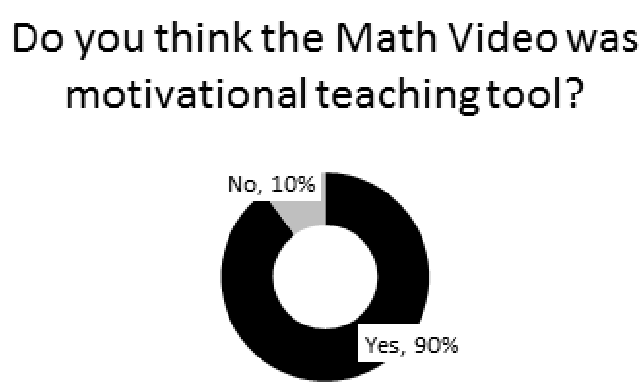

Figure 9: Math Video (WEM) as a Motivational Tool

Overall, 90% of students agreed that WEM had acted as motivational tool and it had helped inspire students to search more about application. Students were also interviewed on the following questions where they were allowed to give more than one answer and also they could choose their own answer. Most favoured answers are listed in the following figure.

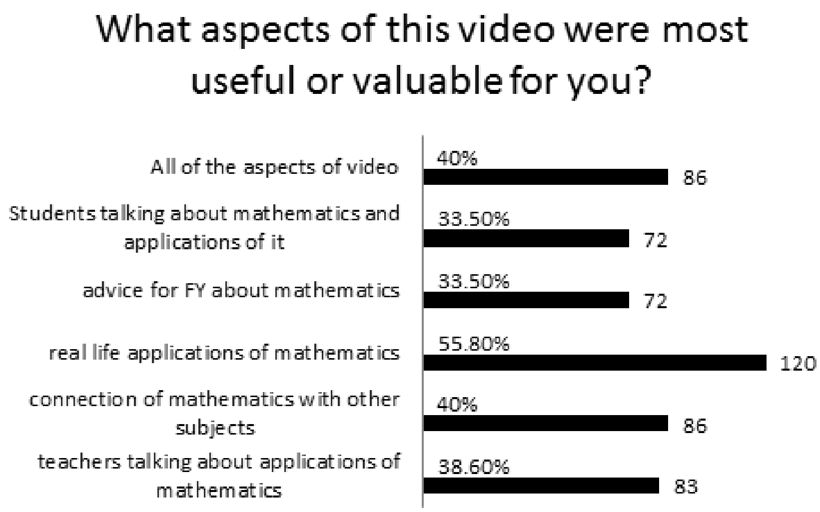

Figure 10: Overall impact of WEM

CONCLUSION

WEM widely left its impact on students. WEM was the first ever surprising experience for almost all students in mathematics classroom. Majority of students have changed their perception towards mathematics and started using internet to find other applications of mathematics. They have started approaching core engineering faculty to relate mathematics with other subjects. Students have understood the importance of mathematics, especially topics covered in Applied Mathematics-I in first year B.Tech at KJSCE. Most of the students considered WEM as one of the best and innovative teaching tools. Students involved in the development process of WEM commented that other than mathematical benefits, development of WEM also helped improve their creativity, vision and other lifelong learning.

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MATHEMATICAL EXPLORATIONS ENCOURAGING MATHEMATICAL PROCESSES IN A CLASSROOM

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In this paper we examine how open mathematical explorations encourage mathematical processes in a classroom. For this we look at two classrooms that were a part of a 9-day talent nurture camp. whose purpose was to give students a flavour of doing science and mathematics. We choose one activity that was implemented in the camp and examine how it fits into the notion of an open exploration. We then look at the implementation of this activity in two different classrooms by two different teachers and examine how far these implementations encouraged mathematical processes. We choose to focus on the processes of visualisation, making conjectures and proving. The preliminary analysis of the sessions establishes that such open explorations have a huge potential in encouraging mathematical processes in the classroom.

Keywords: *Mathematics Education, Pattern, Mathematical processes*

INTRODUCTION

Mathematical processes play a very important part in understanding and doing mathematics. The National Focus Group Position paper on Teaching of Mathematics strongly recommends giving precedence to mathematical processes over content, “Giving importance to these processes constitutes the difference between doing mathematics and swallowing mathematics” (NCF 2006, Teaching of Mathematics). The document identifies processes like formal problem solving, use of heuristics, estimation, approximation, optimization, use of patterns and visualization, representation, reasoning and proof, making connections, mathematical communication. (NCF 2006, ‘Teaching of mathematics’, p iv). Emphasis on mathematical processes helps in reducing the fear of mathematics in children’s minds and in strengthening students’ capacity to ‘do’ mathematics. By mathematical processes, we mean stages that mathematicians go through while doing mathematics. Mathematics education literature abounds in characterisation of these processes. One of the first attempts at studying the nature of mathematical processes and how it is related to content can be seen in Bell (1976), where he identifies symbolization, modelling, generalization, abstraction, and proving as the basic processes of mathematics. Mason, Burton & Stacey (2010) identify conjecturing and convincing, imagining and expressing, specializing and generalizing, extending and restricting, classifying and characterizing, as the core mathematical processes. For the purpose of this paper we choose to focus on three of these processes, namely visualisation, making conjectures and proving.

In order to provide students with opportunities to engage in these processes, teachers need to provide mathematically rich tasks/activities and classroom environment so that students are able to engage actively in mathematical discussion and discourse.

In this paper, we look at one such activity which was conducted in two different classrooms.

We examine the 'openness of the task' in the light of Yeo's framework to characterise the openness of tasks (Yeo, 2015) and move on to analyze the classroom videos and elicit instances where children's engagement in mathematical processes was apparent.

THE OBJECTIVE OF THE CAMP

The classrooms were a part of a larger talent nurture programme called Vigyan Pratibha of the Homi Bhabha Centre for Science Education (HBCSE), which is aimed at supporting high quality and well-rounded science and mathematics education. These classrooms aimed at exploring students' thinking when exposed to an open exploration through patterns.

METHODOLOGY

The data was collected from two classrooms where the same mathematical exploration was being conducted. These classrooms were a part of a summer school held for students from 7 different English medium schools around HBCSE. All the students were Class 10 students (entering). The admission to the summer school was completely voluntary and there was no selection process. The activities were conducted by two different teachers, who both are authors of this paper. One class had 22 students (B – 12 and G – 10) and the other class had 25 students (B – 14 and G – 11). Data sources include classroom observations and classroom videos.

The objective of the activity was to encourage different mathematical processes in the classroom. In the present activity, students explored patterns of squares of natural numbers.

ABOUT THE ACTIVITY

The activity comprised of two different but connected tasks. In the first task, the students were given the table shown in Figure 1 and were asked to observe patterns in the table.

Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Square	1	4	9	16	25	36	49	64	81	100	121	144	169	196	225	256	289	324	361	400

Figure 1

In the second task, the natural numbers up to 400 were arranged in a 8-column table as shown in Figure 2 and the first few square numbers highlighted. They were expected to shade in the remaining squares and look for patterns.

I	II	III	IV	V	VI	VII	VIII		I	II	III	IV	V	VI	VII	VIII
1	2	3	4	5	6	7	8		209	210	211	212	213	214	215	216
9	10	11	12	13	14	15	16		217	218	219	220	221	222	223	224
17	18	19	20	21	22	23	24		225	226	227	228	229	230	231	232
25	26	27	28	29	30	31	32		233	234	235	236	237	238	239	240
33	34	35	36	37	38	39	40		241	242	243	244	245	246	247	248
41	42	43	44	45	46	47	48		249	250	251	252	253	254	255	256
49	50	51	52	53	54	55	56		257	258	259	260	261	262	263	264
57	58	59	60	61	62	63	64		265	266	267	268	269	270	271	272
65	66	67	68	69	70	71	72		273	274	275	276	277	278	279	280
73	74	75	76	77	78	79	80		281	282	283	284	285	286	287	288

Figure 2: Snapshot of the entire table

It was expected that shading in the squares would make it obvious that the square numbers occur only in the first third columns, hinting that the only possible remainder when a square number is divided by 8 is 0, 1 or 4, leading to modular forms of $8n$, $8n + 1$ or $8n + 4$. None of this was explicitly mentioned, and the students were invited to 'look for patterns' expecting to follow along whatever patterns the students came up with, creating opportunities for students to engage in mathematical processes.

Yeo (2015) includes 5 elements in his framework to characterise openness of a task, answer, method, complexity, goal and extension. These tasks are open on the parameters of answer and method, as there are multiple answers and multiple approaches possible. For these tasks, while it is possible to anticipate some of the methods and patterns that students would come up with, it is definitely not possible to come up with an exhaustive list. The task specifies a goal – namely 'find patterns' but at the same time does not specify any particular pattern and is thus open on goals. The tasks are extendable, in that one could go on to modular arithmetic, visualisation of square numbers as the sum of consecutive numbers and so on. Thus given tasks clearly fall under the category of what Yeo calls as open investigative tasks.

The openness of the task provides affordances for multiple answers and discussions around them, thus providing ample opportunity for mathematical communication. The act of looking for patterns privileges coming up with conjectures and the tables and the arrangement in columns provide visual cues to pattern findings. The natural steps after guessing a pattern is verifying it and then proving it. Depending on the 'proof schemes' (discussed later in the paper) (Balacheff, 1988), students have, they may or may not differentiate between these two processes. Thus the task privileges mathematical communication, visualisation, making conjectures and proving among other processes. The tasks also demand very little in the nature of prerequisite knowledge and hence is accessible to all students. Based on these considerations, these tasks were chosen for implementation. We highlight below instances where these process came to the fore.

ABOUT THE CLASSROOMS AND THE FINDINGS

Before presenting the instances of students' thinking and examples of mathematical processes the students engaged in, we would like to describe the classroom practices which supported students' thinking in the classroom which in turn encouraged mathematical processes.

Both the teaching sessions began by asking students to find out patterns from Figure 1 and then share it with the class. Students were given a choice of working individually or working in groups but working in groups was encouraged. They were encouraged to articulate the patterns that they found out verbally or visually and share their findings with the rest of the class. The other students were encouraged to ask counter questions and justifications. Whenever needed the teacher would also help the students in articulating the patterns they found.

At times, the teachers suggested that students use different representations which would make the patterns clearer instead of doing it themselves.

Once they listed out the patterns on the board, it was discussed whether a pattern was true or not. A separate blackboard was used to record students' patterns. There were discussions initiated by the teachers on how to figure out whether a pattern works for all the numbers or what does a statement being true mean, which was essentially driven towards generalization. We noticed a classroom culture where students would refer to each others' pattern by citing their names, pose questions when in doubt, or comment on each others' strategy to prove it.

We now move on to examine the specific processes seen. This is a preliminary data analysis of the classrooms, and the instances that have been reported in this paper are the parts of two 3 hour classes. This analysis is a part of a larger study where we plan to study how open explorations conducted in the classroom encourage mathematical processes.

VISUALIZATION

We believe that visualization plays a central role in helping to find an effective solution for such pattern problems. Kerbs (2003) found that by using a visual approach one can generalize the patterns and Rivera (2007) confirmed that generalizations were based on visualization. And in the instances mentioned below a student is able to figure out a pattern visually. In the task, there were many instances where students have figured out patterns just looking at the number-table.

Instance 1
In class, students were asked to find out patterns from Figure 1.

S1 : Ma'am the sum of the first number and the second number when added with the square of the first number it will give you the square of the second number.

T1 : You heard what he said? [looking at the whole class]

S2 : No, we couldn't hear.

T1 : No, Ok. [looking at S1] You want to come on the board? Maybe drawing is easier for this. What you said no… If you draw that thing it might be a bit easier. [S1 walks towards the board]. So, just look at the tables what he is saying [To the class].

1 (1st number)	**2** (2nd number)
1 (Square of the 1st number)	**4**

Figure 3

S1 : [Writes on the board (See Figure 3)]

T1 : So you have a table right? What he saying is, you look at this [marking what S1 has said]. Right? Now, what he is saying is that you add these three numbers, you will get this fourth number. And he is saying it is always true, [To the class]. You are saying it will hold even if you extend the table, right? [Looking at S1]

S1 : Yes.

T1 : See we all together have to prove it. We can't just write statements like that no? [Talking to the class]

Comments: The student further goes to prove what he has written by saying that, $(x+1)^2$ is nothing but the addition of $(x + x^2 + (x+1))$. This relationship was new to the teacher too.

We see that the students had made mental figures to see the way patterns were emerging. . In other instances, students had just looked at the numbers given in the table and made their own patterns which were geometric.

MAKING CONJECTURES

Polya (1954) talks of the importance of conjectures and 'plausible reasoning' used to support them in the process of creating new knowledge in mathematics. Looking back and perceiving the steps that might have gone into coming up with the Goldbach conjecture, Polya identifies noticing some similarity, a step of generalisation and formulation of a conjecture. As the first step we recognise that 3, 7, 13, 17 are primes, 10, 20, 30 are even numbers and that the equations 3 + 7 = 10, 3 + 17 = 20 and 13 + 17 = 30 - are analogous to each other. We then pass to other odd numbers and even numbers and then to the possible general relation

"even number = prime + prime".

The conjecture is a statement suggested by certain particular instances in which we find it to be true. Now we move to examining if it is true of other particular or atypical cases. For example, the number 60 is even, can it be expressed as a sum of two primes? By a process of trial and error we come to 7 + 53. This makes our conjecture more 'credible'. Our conjecture gains credibility with the number of instances for which it is verified to be true, but it is not established beyond doubt, there is still the possibility of finding an even number that cannot be expressed a sum of two primes. Hence Goldbach Conjecture remains a conjecture almost 300 years after it was formulated.

It is important that students be given an opportunity to go through the process of discovery outlined above – of coming up with a guess, verifying that it is true and trying to prove it. In the process of discovery, the stage of coming up with plausible conjecture is of prime importance. "Anything new that we learn about the world involves plausible reasoning, which is the only kind of reasoning for which we care in everyday affairs" (Polya 1954).

The tasks outlined here provide ample opportunities to engage in this kind of reasoning as can be seen from the following instances.

Instance 2

The class was asked to find patterns in Figure 2. The students were finding patterns and discussing it with their partners or groups and then sharing them with the teacher and the class.

T1: Let's start with more patterns. Did you see any patterns? Yes, S12. Can you show there? [pointing on a board]

S12: It's very complicated.

….

S12: If n [leaves incomplete]

T1: If n is a natural number.

S12: n raised to 4 [teacher wrote it on the board n^4], brackets [teacher made the bracket] n plus one raised to 4 [teacher wrote $(n + 1)^4$ on board] is always divisible by 5 [teacher repeated].

[on board $n^4 + (n + 1)^4$ '! is always divisible by 5]

Some more examples

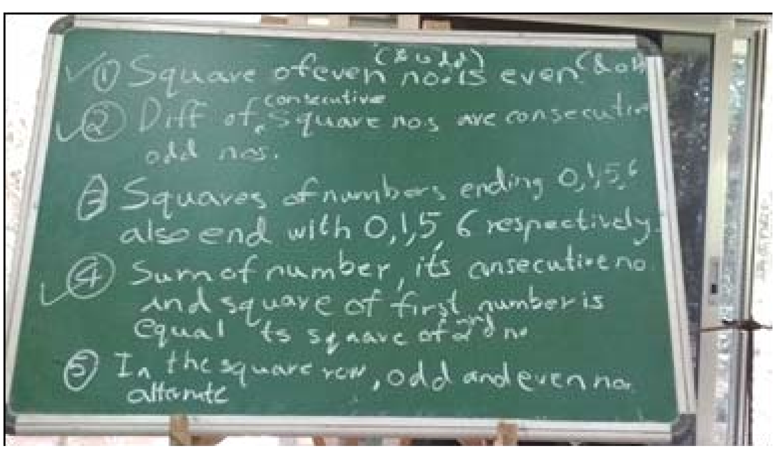

Figure 4: Some examples of students' conjectures

There were conjectures, similar to the ones given above which were a surprise for the teachers themselves. And the teachers also had to figure out strategies to deal with these conjectures then and there. The kind of classroom environment encouraged by the teacher, gave students the confidence to make conjectures, refute them, update them and prove them and a number of conjectures came up.

We believe that, such open mathematical tasks/activities give students a taste of how mathematics is done, as they go through the process of coming up with ideas that do not work, examining and rejecting, modifying their own statements and seeing mathematics in the making. This is very different from what they do in their school mathematics. In these activities, the students were in charge and actively driving the discussion instead of passively learning definitions and theorems in the textbook. Here they come up with their own conjectures, choose the patterns they would like to investigate and the ways to prove them. In a way, this gives them the ownership of whatever that they are doing which might help in removing the fear of mathematics and the feeling of insecurity in doing mathematics.

PROVING AND PROOF SCHEMES

Students difficulties with proofs are well documented in mathematics education literature. One of the most common difficulties that students have with the concept of proofs is that they believe that a non-deductive argument, like say verifying for a few cases constitutes a proof (Weber, 2003). Balacheff (1988) differentiates between pragmatic and conceptual proofs and discusses four main types of proofs in the cognitive development of the concept of proofs. ‘Naive empiricism’ which involves asserting the truth of a result after verifying several cases is the most rudimentary but obviously inadequate proof scheme identified by Balacheff. One important aspect of understanding the concept of proof is to move from ‘it is true because it works’ scheme of the naive empiricism to establishing the truth by giving reasons. This is not an easy shift to make. However, the instances described below indicate how this happened as a matter of course in the context of these open tasks.

Instance 3

The class was asked to find out patterns from the given Figure 1.

S5 : The numbers between the square numbers are increasing by 2.

T2 : [repeated the statement] What does that mean?

S5 : Between 1 and 4, it is 2 and 3. Between 4 and 9 it is 5,6,7,8

T2 : How will I know what you are saying is correct? I take any big square number how will I know how many numbers are going be there in between?

S5 : I know!! You take the root of the first square number and then multiply it by 2 you will get to know how many numbers are there.

T2 : What you are saying now is more than what you said earlier. First, you said the numbers in between are increasing by 2, but now you said to know the number you take the square root of the smallest number and multiply it by 2 to get the numbers in between. [Discussion with the class]

T2 : I want the class to pay attention here, S6 is saying S5's pattern is proved [To the class]. Why? Can you explain to the class? It's ok go ahead explain it [talking to S6]

S6 : [Stand up at his place] His first pattern that two numbers has been added in between [looks for the exact word in the book] his pattern is been proved in Table 1.2. If we see numbers between 1 and 4, two numbers are there. Between 4 and 9, four numbers are there. Between 9 and 16, six numbers are there and so on if we see all the numbers between the two squares from 1 to 20. So, we can see that the numbers in between are 2, 4, 6, 8 and so on. [Teacher repeated by showing it on the table what S6 said]

S7 : [Immediately] Ma'am, this is not proving, this is just verifying.

Instance 4

A student has come with the pattern that if you multiply two consecutive natural numbers and then add the larger consecutive number to that product you will get the square of the larger number.

T1 : Do you think this is correct?

Class (coherently): Yes.

T1 : But, always will be correct?

Class (again coherently): Yes.

T1 : So for example, if I have 1027, 1028 and square of 1027, if I whatever multiply and I will get the square of 1028? Are you actually saying that? [and wrote on the board]

S8 : Yes ma'am.

T1 : What do you think S9?

S9 : It could.

T1 : So it might not be?

S9 : [Nods the head].

T1 : So what does one do when this happens? As S9 is saying it might work or might not? What does one do in such a situation?

S10 : Make it a theorem.

T1 : Make it a theorem. So, how do you make something a theorem? S11 how do you make something a theorem?

S11 : By proving it.

T1 : Yes, right. So you got a lot of theorems here. [pointing at the patterns students have come up with] Actually some of the theorems I have never thought about it. So, let's start proving these theorems.

Comments: In the above classroom dialogues, it is evident that students are capable of making conjectures by observing patterns and differentiating between proving a result and verifying it, which is very crucial in understanding mathematics as a discipline. In the instance mentioned above the need to prove the students' patterns came from students themselves. Both the classes went on to prove some of the conjectures they came up with as well.

We believe that the open nature of the task provided opportunities for classroom discussions as exemplified above, underscoring that verification and proof are not one and the same. Further analysis is needed to identify the features of the task or the classroom practices that enabled the move from naive empiricism to generalisation.

CONCLUSIONS

Open explorations like the one which was conducted in the reported classrooms offer opportunities for making conjectures and encourage a multiplicity of ways of thinking, ideas, approaches, and answers as compared to goal-directed problem-solving. Such explorations encourage a classroom environment which is open to discussion among students and also gives students space to makes mistakes which are an intrinsic part of the classroom process; Such open tasks shift the focus from finding the right answer or verifying and proving a given conjecture to coming up with conjectures, refuting and updating them and in general engaging in the process of making mathematics. This encouraged participation of the majority of students in both the classrooms. The openness of the activity made it possible for every student in the class to create their own mathematics. The potential of open tasks over goal-driven problem solving in encouraging mathematical processes and identification of the characteristics of tasks that aid this needs further study.

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Strand 4

Discipline-based Education Research with Emphasis on Undergraduate Science Education

PARTICLE IN A CONFINING POTENTIAL: DEVELOPMENT OF CONCEPT INVENTORY AND IDENTIFYING STUDENTS ALTERNATIVE CONCEPTIONS

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The problem of a particle in a confining potential in introductory quantum mechanics is one of the starting points beyond Bohr model to mathematically explore how quantization arises and how with each quantized level a corresponding wave function can be attached via the solution of Schrodinger equation explicitly. This problem offers a wonderful opportunity to identify alternative conceptions of students as they make a transition from the world of deterministic classical mechanics to the world of probabilistic quantum mechanics and start seeing its efficacy in explaining phenomenon at the microscopic level. The effort is to take students from alternative conceptions to physically correct concepts. In this paper, we present the developed concept inventory for a particle confined in a box with rigid walls limited to one dimension. The results of the implementation of the inventory are compared with an expert view for each of the question items validated and tested for implementation. Concept inventory is designed and tested at the undergraduate, Bachelor of Science (B.Sc.) level students, who study these concepts not only within quantum mechanics but also in the solid-state physics course each of credit 4, during their three year, six-semester programme.

INTRODUCTION

Quantum mechanics is a physical theory, which has brought a paradigm shift in the understanding of the matter at the microscopic level, and has made us understand the real world. It is as relevant in the macroscopic world as in the microscopic world, because laws of classical physics follow from the laws of microphysics. It comes up with a good useful theory, which makes physical interpretations plausible and understandable by offering means for quantitative interpretation of experimental observations ((Hadzidaki, Kalkains & Stavrou, 2000; Ashcroft & Mermin 1976; Mott & Jones 1958). It is without doubt a key to understand the fundamental structure of matter, which is a collection of large number of microscopic particles (10^{23}). Even during the study of courses such as solid state physics course learners' come across application of various concepts drawn from quantum mechanics (Kittel, 1985). In 1970, Richard Longini in his book *introductory quantum mechanics for the solid state* (Longini, 1970) underlined the importance of basic ideas of quantum mechanics for atomic binding and for solids. However, the foundation of quantum mechanics is probabilistic in nature requiring epistemological issues, which need to be addressed for converting beliefs steeped in classical mechanics to beliefs of the expert regarding quantum mechanics (Styer, 1996) to appreciate its real life applications which has influenced deeply the technological advances made in the 20th century.

A number of conceptual surveys/inventories in different physics domain, to identify the alternative conceptions have been designed and developed by physics education researchers ((Hestenes, Wells & Schwackhammer, 1992; Thortron & Sokoloff,1998; Maloney, O'Kuma, Hieggelke, & Heuvelen 2001; Krause, Decker, Niska, Alford, & Griffin, 2003; Richardson, Morgan, & Dantzler, 2003; Sharma & Ahluwalia, 2015) to as certain alternative ideas held by the learners which are entirely different from the expert view. Sometimes these alternative ideas form a significant barrier to learning correct expert view. In recent years, many studies have been undertaken on students' understanding and alternative conceptions held in quantum mechanics (Belloni, Christian, & Cox, 2006; Zollman et al., 1999; Zollman, Rebello, & Hogg, 2002; Singh, 2007; Singh, 2001; Muller & Wiesner, 2002; Bao & Redish, 2002, Cataloglu, 2002; McKagan, Perkins, & Wieman, 2010; Wuttiprom, Chitaree, Soankwan, Sharma, & Johnston, 2006, 2008; Sadaghiani, 2005). The exploration and research of such alternative conceptions can help teachers and researchers to know how learners perceive particular knowledge and justify their inferences. The information of alternative conceptions can also be helpful for teachers in deciding their teaching strategies to improve student understanding of the concepts.

In this paper, the development of a concept inventory of quantum mechanics for undergraduate, Bachelor of Science (B.Sc.) three years degree course has been discussed. Further, in the paper students' some alternative conceptions identified on one of the theme of concept inventory is presented.

METHODOLOGY USED

The methodology used for developing the concept inventory on quantum mechanics is explained below. The tool (consisting of only one theme "particle in a box") discussed in this paper is a subpart of the concept inventory (Kaistha, 2014) consisting other themes as well. Table 1 provides the concept profile of this theme which can act as a prerequisite for solid state physics course also.

i. Identification of concept domain

Different quantum mechanics concepts which are required to understand various topics of solid state physics course were identified first.

ii. Identification and defining of themes

After identifying the concepts of quantum mechanics, six themes (i) basics of quantum mechanics (ii) wave particle duality (iii) uncertainty Principle (iv) wave function and Schrödinger equation (v) particle in a box and (vi) Tunneling Effect were selected for the concept inventory.

iii. Delphi Study

To validate the above defined themes a research technique called Delphi Study was used. It involved interactions and discussions with the experts of the concerned field. In this case, the process was carried out with almost ten faculty members of physics department of local undergraduate colleges in Shimla, and one Engineering Institute of Shimla.

iv. Interactive session with students

An interactive session was carried out with the third year students of B.Sc. three years degree course. These students had earlier gone through the quantum mechanics and solid-state physics courses. This session helped us to understand the students' difficulties and ideas in the understanding of quantum mechanics and solid state physics courses and hence designing of the questions.

v. Drafting of multiple choice type questions

The drafting of multiple choice question items of the concept inventory was done by consulting various textbooks and other resources. To get structural validity a draft of concept inventory was sent to 15 experts all teachers in colleges or universities all over the country to check mark and point out any

- deviation from concept specificity of the question item
- ambiguity as regards physical concept involved
- ambiguity of wording and diagrams in the sent items
- choices/ alternative options, which in their opinion are not good distracters etc.

vi. Validity (Item Analysis)

To check the quality of each question item, *item discrimination test*, *item difficulty test* and *point biserial coefficient test* were performed on each question item.

vii. Reliability (Test Analysis)

To check the reliability of the whole test, Cronbach Alpha coefficient test and Ferguson Delta test were performed (Kaistha,2014) The instrument developed on alpha coefficient 0.92, which seemed to be reliable (Nunnally, 1978).

MODE USED

As an exploratory testing, the assessment tool (Appendix A) was administered in the form of pre-test and post-test at the beginning and at the end of the quantum mechanics course to undergraduate students. This course was taught to them in the second year of their three years degree (B.Sc.) program by traditional classroom methodology. 128 undergraduate students (UG), studying in four different undergraduate colleges of Shimla, affiliated to Himachal Pradesh University, Shimla, India, participated in it. The tool was also administered to 25 postgraduate (PG) students, studying in Physics Department, Himachal Pradesh University, Shimla. The PG students study an advance course on Quantum Mechanics in their master's program. Along with it the tool was also administered to 50 teachers, teaching physics in the different colleges all over the country (India), and undergoing a three weeks refresher course in physics, at Academic Staff College (ASC), Punjab University Chandigarh, and Academic Staff College (ASC), Himachal Pradesh University, Shimla. To PG students and to the teachers the test was administered only as pre-test. All the target group members were given two weeks advanced intimation for the administering of the test and they took almost an hour to finish the test.

Theme	**Concept Profile: Topics of Solid State Physics course in which concept(s) is/are of theme used**
Particle in a box	Free electron theory of metals, Somerfield's quantum theory of free electron gas model, lattice vibrations, harmonic oscillator, analogy of phonons with photons, band theory of metals and nano science

Table1: Concept Profile of theme-'particle in a box'

DISCUSSION AND ANALYSIS

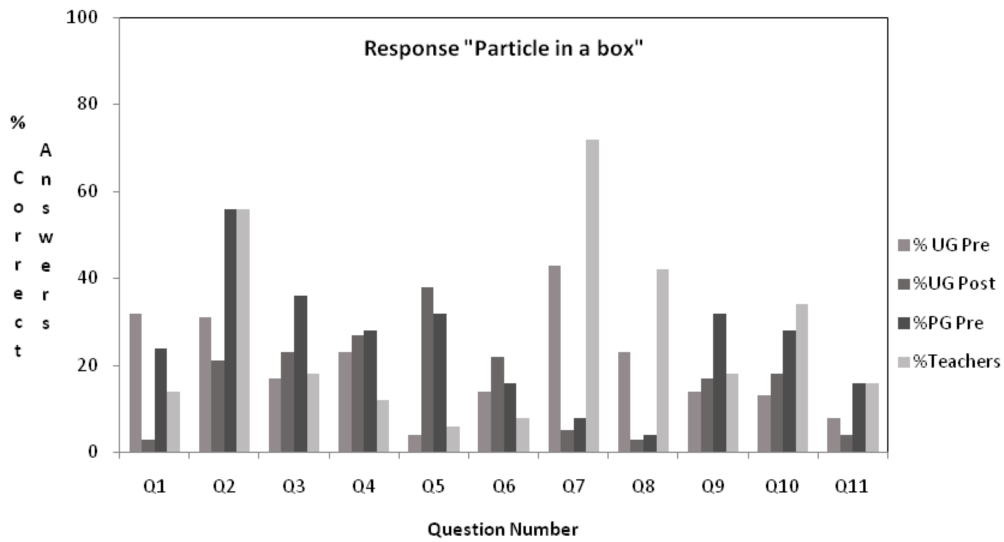

Figure 1: Response of UG, PG students and Teachers on Theme (Particle in a box)

Particle in a box

Particle in a box is a very interesting model in Quantum Mechanics which is mainly used as a hypothetical example to illustrate the differences between classical and quantum confined systems. It is also one of the simple Quantum Mechanics problems, taught in undergraduate physics courses and can be solved analytically without approximations. For example in case of metals, while explaining free electron model, the situation obeyed by particle in a box is used. It is assumed there that conduction electrons are free of the influence of local electric field of atomic origin; however, they are kept inside by the strong forces. Thus, potential is assumed constant inside the material and very large at the surface of metals and holding the electrons inside. Also in explaining Kronig Penny Model which is an idealized one dimensional model of a crystal and exhibits many features of the electronic structure of real crystals, having potential energy of an electron in an infinite sequence of periodically spaced square wells, this concept is used.

The assessment tool on theme **"particle in a box"** involved eleven questions and was administered to UG, PG students and teachers. Figure1 gives the response on the tool by UG, PG students and teachers.

Q1 was based on the fact that, zero energy leads to undefined wave function. 24% of PG students, 14% of teachers and 32% of UG students gave the correct answer in the pre-test. The score of UG students came down to 3% in the post test. Q2 was to compare the ground state energies of hydrogen and helium particles using their masses and to see how energy changes with mass. The percentage of correct answers was 56% for both PG students and teachers, whereas, for UG students percentage was 31% in the pre test which reduced to 21% in the post test. In Q3 students were supposed to differentiate between the dependence of energy on one (n) quantum number, two quantum numbers ($n_{x,}$ n_y) and three quantum numbers ($n_{x,}$ $n_{y,}$ n_z), to check manifestation of degenerate energy levels. Both PG students as well as teachers scored very less in it 36% and 18% respectively. UG students scored 17% in pre test which was increased to 23% in post test. In Q4 students were asked to compare three systems; proton, electron and a billiard ball for lowest energy. In this question, teachers scored 12% less than both UG (23% in pre test and 27% in post test) and PG students (28%). In Q5 students were supposed to appreciate the fact that for a particle in a box, negative value of n in k= nð/L makes "x negative and n=0 makes wave function zero and hence, not possible. Both UG students and teachers scored very less (4% and 6% respectively) than PG students 32%. However, in post test UG students scored 38%. In Q6 solution of Schrodinger equation for a particle in a box in an interval (0, a) was asked. Again, the score of teachers (8%) was less than both UG (14% in pre test and 22% in post test) and PG (16%) students. Q7 to Q11 were graphical questions. In general it was found that students as well as teachers found these graphical questions difficult and scored quite less. Q7 dealt with solving time independent Schrodinger equation for a particle in a square well of width "a". Here teachers scored 72% but scores of both UG (43% in pre test and 5% in post test) and PG (6%) students was very less. in Q8 solution of time independent Schrödinger equation for an infinite square well cantered at the origin was asked. All these questions Q6, Q7 and Q8 required the application of appropriate boundary conditions and then finally normalizing the wave functions.

Q.No	Concept	Alternative Conceptions/misconceptions identified in response to the questions and interviews held later to know how students arrived at their marked responses.
1.	Particle in a box	The energy of bound state and unbound state is same. Students did not have idea that, in bound state problems, energy is found to be quantized & in unbound state, where particle is not trapped, particle will travel as a travelling wave of amplitude Ψ
2.	Ground state energy of H_2& He	Ground state energy of hydrogen and helium is same. No notion that for ground state since the mass of helium is more than hydrogen therefore energy is less
3.	Degeneracy of energy level	Meaning of degeneracy was not clear
4.	Energy level of different systems	Not able to see the Relationship between energy and length of confinement
5.	Allowed boundary conditions	No idea that if n=0 is taken then Ψ and hence probability will become zero & if n is negative then uncertainty principle will give Δx negative, which is not possible.
6.	Wave function from Schrödinger equation	It should vanish at boundaries
7.	Time independent Schrodinger equation for infinite square well	Found difficulties in interpreting meaning of boundary conditions
8.	Time independent Schrodinger equation for infinite square well at origin	Shifting of coordinate system to origin does not have any effect on solution of Schrodinger equation
9.	Relationship between wave number & wave function	Found it difficult to relate wave number & wave function
10.	Probability of finding the particle	Probability amplitude is a place where possibility of finding the particle is most. At center probability is maximum
11.	Expectation value of position	Probability density & expectation value are the same

Table 2: Alternative conceptions in various concepts of Theme "Particle in a box"

After the administration of the tool, to find out why the students have ticked a particular option while attempting the question item of the inventory and also to get an idea of their thinking process interviews were also conducted. We chose 36 UG students of one of the undergraduate colleges and 25 PG students of Physics Department, Himachal Pradesh University for this purpose. Table 2 gives alternative conceptions identified in various concepts of Theme "Particle in a box" in UG and PG students.

CONCLUSIONS

Alternative conceptions originate due to various personal experiences, observations perceptions and prior knowledge which students bring with them in the class room. They are hard to change and may create conflict with knowledge presented by conventional teaching. A student may make sense of the new information in terms of his/her own alternative way of thinking about the topic. Instructional approaches that assess students understanding of the concepts and change their alternative conceptions can act as an effective tool in the classrooms. Physics Education Research based diagnostic assessment tools play an important role to improve student learning as they help to improve their conceptual knowledge. Sometimes, teachers, overestimate our students' prior knowledge without checking the reality, and try to build new knowledge on a shaky foundation. Introductory undergraduates' classical physics courses focus on realist perspective and explain both present and future properties of a classical system. However, such a perspective becomes problematic for introductory quantum mechanics learner and hinders the understanding of the same models applied elsewhere for example in solid state physics course. The objective of the present work was to develop and design a validated and reliable assessment tool to investigate students' understanding of quantum mechanics concepts which may be used prior to the teaching of courses such as solid state physics.

In this paper, statistical analysis, based on the sample of 128 UG students, 25 PG students and 50 teachers was presented which indicated that both students as well as teachers had limited and superficial understanding of fundamental concepts involved in the understanding and usage of 'particle in box'. This exploratory study brought out alternative conceptions held not only by students but by teachers as well which also reflects on the need for teacher orientation also towards correct concepts In case of UG students we found that traditional lecture based teaching methodology was not effective enough to change their conceptions. This obtained information in this theme could become the basis for developing some teaching aids and further exploration in improving the ground situation. Technology based environment like the one simulations of certain phenomenon can be used as the pedagogical vehicle to increase the content knowledge (Sharma & Ahluwalia, 2012) and to resolve a false notion about the concept.

Future plans

In future we intend to do more intensive study by modifying some of the question items of the concept inventory focusing on addressing the alternative conceptions held by the students and then administer it again to UG and PG students for further analysis.

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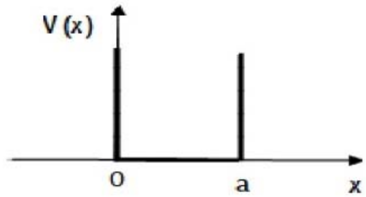
Appendix

1. A particle will not exist inside a rigid box if its energy is:



(a) zero (b) ∞ (c) < 0 (d) > 0

2. Ground state energy of Helium atom in an infinite rigid box as compared to ground state energy of hydrogen atom is:
(a) higher (b) lower (c) equal

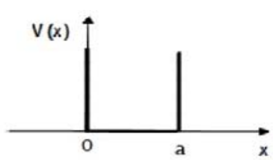
3. A particle will have degenerate energy levels in:
(a) a one dimensional box (b) a square two dimensional box (c) a cubic three dimensional box

4. The lowest energy level for a electron in a box of length 5.0×10^{-10} m, a proton or a neutron of mass 1.67×10^{-27} kg in a box of width of nucleus (L= 1.1×10^{-14}m) and a billiard ball (m= 0.2 kg) bouncing back and forth between the cushions of frictionless perfectly elastic billiard table (L=1.5m) will be
(a) 1.69×10^{6}eV, 1.5 eV, 7.5×10^{-48} eV (b) 7.5×10^{-48} eV, 1.5 eV, 1.69×10^{6}eV,
(c) 1.5 eV, 1.69×10^{6}eV, 7.5×10^{-48} eV

5. For a particle in a box, we choose $k=n\pi/L$. To fit the boundary condition that $\psi = 0$ at $x = L$. The values of n are :
(a) n = 0,-1,-2,-3,…… (b) n = 1,2,3,……. (c) n = 0,1,2,3…….

6. The solution of Schrödinger equation for a particle in a box on the interval
$x = [0,a]$ is
(a) $\psi = (\sqrt{2}/a) \sin(n\pi x/a)$ (b) $\psi = (\sqrt{2}/a) \cos(n\pi x/a)$ (c) $\psi = (\sqrt{2}/a) \tan(n\pi x/a)$

7. An electron is confined to a one-dimensional, infinitely deep potential energy well of width a depicted below.
$V(x) = 0$, for $0 < x < a$
$= +\infty$, for $x < 0, x > a$



Solution of the time-independent Schrödinger equation with appropriate boundary conditions for this square well is

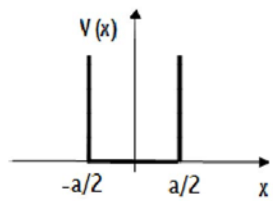
(a) $\varphi_n(x) = (\sqrt{2/a}) \sin (n\pi x/a)$; n=1,2,3…….. (b) $\varphi_n(x) = (\sqrt{2/a}) \cos (n\pi x/a)$; n=1,2,3……..

(c) $\varphi_{n(x)} = (\sqrt{2/a}) \tan (n\pi x/a)$; n=1,2,3…….

8. How does your answer change for the infinite square potential well cantered at the origin?

V (x) = 0, for — a/2 < x < a/2

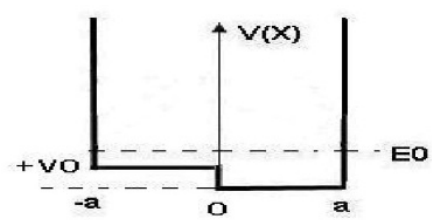
= +∞, for x >a/2



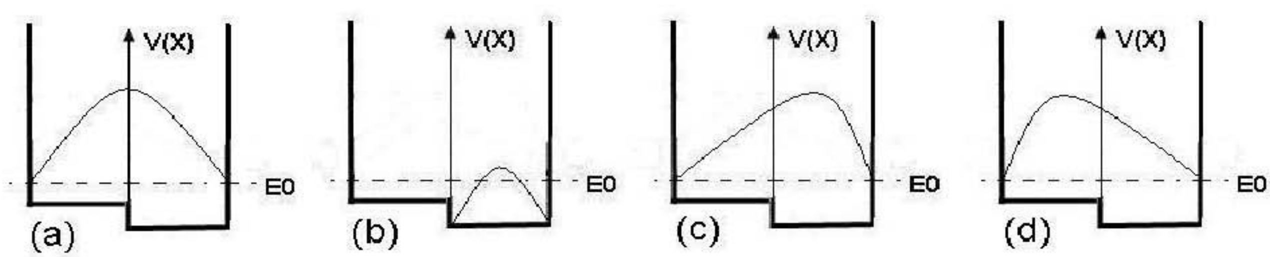
(a) $\varphi_{2n-1} = (\sqrt{2/a}) \sin (n\pi x/a)$; n=1, 2, 3……. b) $\varphi_{2n-1} = (\sqrt{2/a}) \cos (n\pi x/a)$; n=1,2,3……..

(c) $\varphi_{2n-1} = (\sqrt{2/a}) \tan (n\pi x/a)$; n=1, 2, 3……

9. The plot below shows a potential energy function V(x) versus x, corresponding to an asymmetric infinite well. The infinite well is of the width 2a, with impenetrable walls at x= a but where V(x) = + Vo for x between (-a, 0) and V(x) =0 for x between (0, +a)



Of the figures below, which is /are more most likely to be physically acceptable energy eigenstate solutions for the time-independent Schrödinger equation for this well ?

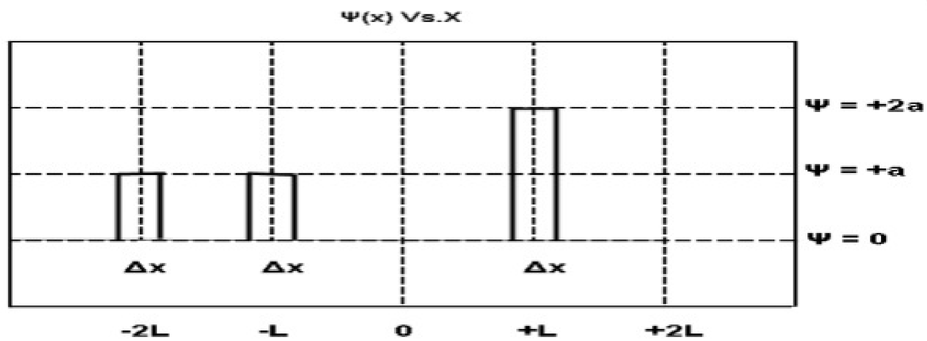


(a) b (b) a (c) d (d) c

10. Consider an infinite square well of width L with a single electron in it. If someone performs a measurement of the electrons' energy and tells you that they found the electron to have energy of n=2 eigenstate, at what positions is the electron most likely to be found?

(a) L/2 (b) L/3, 2L /3 (c) L/4, 3L/4 (d) 0, L/2, L (e) probability is same everywhere.

11. The figure below shows a plot of a wave function $\psi(x)$ versus x, over the range of (-2L, +2L). The wave function vanishes for all other values of x. What is the expectation value of x?



(a) < x > = 4L/6 (b) < x > = - L (c) < x > =0 (d) < x > = L/6 (e) < x > = - L/4

INDIAN STUDENTS' UNDERSTANDING OF PARTICULATE NATURE OF MATTER

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Understanding of Particulate Nature of Matter is the foundation for learning chemistry. Appreciating this fact, the topic finds space in the school science curriculum across the globe. This topic is abstract so students find it difficult to understand. This paper is an attempt to identify common alternative conceptions related to the particulate nature of matter amongst students in India.

INTRODUCTION

"If, in some cataclysm, all of the scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis that *all things are made of atoms — little particles that move around in perpetual motion, attracting each other when they are a little distance apart but repelling upon being squeezed into one another.* In that one sentence, you will see, there is an enormous amount of information about the world if just a little imagination and thinking are applied."

The above statement by Richard Feynman describes the importance of atomic theory in science. Atomic theory is the foundation of science, thus the foundation of science education as well. For comprehending science whether it is chemical reactions, nuclear behavior, chemical bonding, shapes of molecules; understanding the atom and its structure is indispensable. It is therefore not surprising that the atomic theory is an essential part of the science curriculum across the globe. The need for learners to appreciate the particulate nature of matter drives the inclusion of the topic in the school science curriculum. Not surprising, school curriculum across the globe has given due credit to particulate theory. The theory is introduced to students in the middle school who are in the age group of 11-13 years.

Atomic Theory is a difficult concept with abundant alternative conceptions in the mind of the learner. Alternative conceptions are frequently observed in the student's understanding of atoms. (Nakiboglu, 2003; Park and Light, 2009). Lack of understanding of the theory can be attributed to the abstract nature of the topic. The cognitive readiness of the students is essential to understand abstract topics like atom and the structure of an atom. Therefore until a child reaches the formal operational stage, the introduction of this topic will be a futile exercise. The cognitive preparedness of the child is foremost for curriculum development, it should be cognitively valid (National Curriculum Framework, 2005) [NCF]. Keeping the developmental phase of learners in mind, the National Research Council USA (1996) recommended the introduction of the topic in Grades 9 -12, which is the same in India as well, barring a few exceptions. Following the guidelines of NCF 2005, the Atomic theory is introduced in grade 9 in the CBSE curriculum. The child has attained the age of 14 years when he enters this grade. According to Piaget, this child is now capable of abstract reasoning.

Another problem inherent with microscopic particles is the inability of the students to 'see' the particles leading to association and analogy with a macroscopic system at least initially to understand the abstract topic. The structure of an atom is associated with the 'watermelon and its seeds' as in the case of the Thomson model or 'solar system' in the case of the Rutherford model. The initial engagement with these analogies is so strong that the student falls back to these models time and again.

To add to the problem is the association with the term 'model'. Models used as intellectual tools to aid scientific inquiry are seen as students as a replica of reality. (Grosslight, Unger, Jay, & Smith, 1991, p. 799). Students assume scientists have 'seen' the atom using some sort of special instrument like a special microscope. The colorful 'images of atoms' that are readily available have further strengthened this belief of students. The computer-generated models of atoms appear in different publications of scanning tunneling microscope as 'images of atoms'. These images mislead people. These are assumed to be 'atom' as seen through the scanning tunneling microscope (Harrison & Treagust, 1996). Therefore, the student's belief in being able to see an atom is strengthened.

Molecules are too small to be seen, but these can be seen using some "magnifying lenses". This belief is deep, even after repeated instruction, students feel even if faintly, an atom can be seen. Even after the repeated emphasis on the fact that even with the most powerful microscopes atom is not visible, this alternative conception stands. (Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993)

The researcher came across this strong conviction of scientists have seen an atom while an informal conversation with her students. "I have not seen an atom, but scientists have. I saw the images on the INTERNET" a student said. "Like the model of an internal combustion engine or like the model of kidneys and heart, is the model of an atom" she added. The response can be related to the study by Horton (2007). In the study on alternative conceptions in chemistry, he found that none of the students under study understood that models were not depiction of reality. There was a great difficulty encountered by the students in understanding something they were not able to see.

The content and diagrams that appear in the textbooks add on to the woes. Joshi & Sudhir (2017) question the treatment of this important topic in a superficial manner. The diagrams, they write, are misleading. Expansion of solids on heating is greatly exaggerated and decrease in density of liquid on changing to gas is under represented. This leads to alternative conceptions related to densities of the three states of matter. These problems, related to abstractness of the topic, are responsible of mushrooming alternative conceptions amongst students and not surprisingly also amongst pre service and in service teachers (Kikas, 2004; Nakiboglu, 2003; Haidar, 1997).

Particulate Nature of Matter

Introducing atom, molecule and ion to a child who does not comprehend particulate nature of matter is a futile task. Distinction between the macroscopic properties of matter and the properties of particles is not clear to majority of students. The properties of bulk of matter are transferred to individual particles. The commonly held alternative conceptions in this topic are:

Matter is Continuous

Doran (1972) listed alternative conceptions that commonly occur related to particulate nature of matter. The most common one is considering matter is continuous. The idea of existence of empty space is not internalized by students. They believe there is no space between particles of matter. There is 'nothing' between the particles is not accepted by students. The particles are either in contact (Nakhleh, 1992) or float in some medium (Andersson, 1990; Harrison, 2001) or particles have something like air in between them, (Lee et al., 1993) is a strongly held notion.

According to Lee et al. (1993), this strongly held notion includes 'various kinds of 'stuff [or air] between molecules' (p. 257). Andersson (1990) and Harrison (2001) both found textbooks containing diagrams like Figure 1 where the line across the top tells students that water molecules are floating in some other 'stuff! The students interpret the line on the top in diagrams like figure 1 as water molecules are floating in some other 'stuff!'. Study by Griffiths & Preston (1992) echoes similar results.

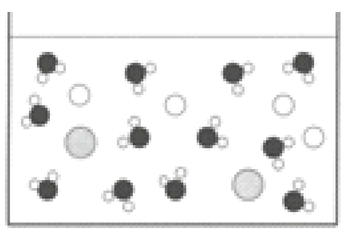

Figure 1: A model of a liquid in a container with surface line implying that the particles are suspended in another substance

Particles of Matter Do Not Move

Many students believe that particles of solid are static. The particles are tightly held and are rigid so no motion is possible in solids. Doran (1972) and Lee et al. (1993) identified students are unable to value the notion of movement at particulate level. The movement of particles in gases is seemingly easily appreciated by students. Though, the belief that when some gas is sucked out of a container, the gas does not fill the container, points at an alternative vision about gas particle. (Nussbaum & Novick, 1982).

Spacing between Particles

Overestimation of distance between particles of liquids is frequently encountered alternative conception. Students however view particles of liquid at a distance that is somewhere intermediate of solid and gas particles. Scientifically, the spacing between solid-solid, liquid- liquid and gas-gas particles is about 1: 1: 10 (Andersson, 1990; de Vos & Verdonk, 1996). Commonly held student view about particles is that: solid particles are in contact, liquid particles about a particles away and gas particles three to four particles away(Harrison, 2001).

The perception of inter-particle distance between different states of matter is directly derived from the textbook representations. Figure 2, shows the depiction of space between particles of solid, liquid and gas from the NCERT Science textbook (class IX). The diagram is misleading. According to this diagrammatic representation, the density of solid would be at least twice that of liquid and that of gas four times the liquid state. This is not true for any known substance. (Joshi & Sudhir, 2017)

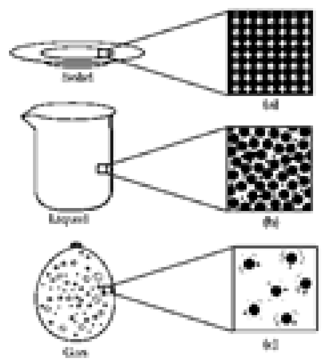

Figure 2: Depiction of distance between particles in solid, liquid and gas.

Properties of Substance are Properties of Particles

Macroscopic properties like colour, malleability, electrical conductivity are considered to be properties exhibited by each individual atom. Ben-Zvi, Eylon, and Silberstein (1986) in their study found nearly 85% students of grade 10 from different schools in Israel thought properties of matter are manifested by an atom. Only 14.9% of the students out of a sample of 288 stated that an atom cannot be isolated or the properties like colour, malleability, conductivity are properties of cluster of atoms.

Atom appears in multicolored images in modern textbooks. These add on to students conceptions of colour of atom. The difference in colour of reactant and products can be used to debate on colour of atom (Albanese & Vicentini, 1997).

Joshi & Sudhir (2017) also reported teachers believe an atom of copper is a better conductor of heat and electricity than an atom of mercury. Also, measurement of temperature of an atom is possible, provided we have the correct instrument. Therefore, teachers attribute bulk properties of matter to properties of the constituent particles. The students are thus likely to develop these alternative conceptions.

A study from Israel conducted by Ben-Zvi et al., (1986), too voices concern about students understanding of atomic theory. Responses of nearly 67% of the students from a sample of 300 high school students, reflected that the ‘continuous model’ of matter was deep rooted. They knew the particulate model but were not able to internalize the concept. For them, atom has same properties as the substance and atoms of solid and gas are different.

The views about particulate nature of matter of 54 prospective elementary teachers of Indiana University, Kokomo, Indiana were studied by Gabel, Samuel and Hunn (1987). The examination of students drawings depicting what happens to particles after physical and chemical change, revealed distorted understanding of particulate nature of matter. The diagrams show change in size of constituent particles when the phase changes and gaseous particles in an ordered arrangement rather than random arrangement. After decomposition reaction, the molecules were still intact as if in a physical change. The misconceptions (author uses this term) related to change of size, no change in inter-particle distance and arrangement as well as poor understanding of physical and chemical change is prevalent.

Study of perceptions about particulate nature of matter in the United States also hints at the struggle of students in comprehending the topic. A sample of 87 high school and middle school students, of schools ranked for their academic performance in US was assessed for their conceptual understanding of particulate nature of matter. Aydeniz & Kotowski (2012) reported the following misconceptions (term used by authors) held by significant number of students: (i) During phase change, chemical composition of the substance changes. The author cites example of students stating boiling of water involves breaking of bonds between hydrogen and oxygen. They visualize phase change as a chemical change rather than a physical change. (ii) Nearly 70% students think a gas formed during change of state (boiling or sublimation) weighs less than the liquid or solid. The “law of conservation of mass” is not internalized by the students. The analysis reported possible reason for such a misconception was students’ belief that the size of molecules changes during phase change.

Students (sample of 20) at the Education Department of the University of Cyprus who opted for a compulsory science course had conflicting views regarding particles of matter. Valanides (2000) cited lack in understanding of empty space between particles, constant motion of particles in all states of matter, particles do not expand or contract during phase change and particles do not melt during the process of melting.

Looking at studies from Africa, similar problem in understanding of particulate matter have been reported. A study of 30 high school pre service teachers, showed lack of understanding of effect of phase change on size of particles. The study was conducted by Banda, Mumba, Chabalengula and Mbewe (2011) which reported 89.7% of the sample associated melting and freezing result in change in size of the particles. Similarly, more than 75% associated vaporization and condensation involves change in size of particles. However, the understanding of distance between the particles, speed and number of particles was in accordance to scientific understanding for nearly 70% of the sample.

The only study from India, which the researcher came across was by Chakraborty & Mondal (2012). The sample was 189 students of grade 9 of four schools situated in Murshidabad district of West Bengal, India. The students were reported to have difficulty in the understanding of mass number, atomic nucleus and shells. No other study was available from India. The researcher decided to conduct a study to find out the alternative conceptions related to particulate nature of matter held by students of grade XI in India.

METHODOLOGY

The study was conducted in two private schools in National Capital Region. The students, who chose science stream in grade XI, were chosen as sample. These students have studied particulate nature of matter in detail in grade IX. The sample of 60 students was selected on basis of section allocation done by school.

A questionnaire was prepared to test the understanding of particulate nature of matter. The questionnaire consisted of 15 multiple choice questions (MCQ) and 4 open ended questions. Out of the 15 MCQ 11 were taken from Particulate Nature of Matter Assessment (ParNoMA) Yezierski & Birk (2006) and rest from Merritt (2010).The open ended questions were taken from studies by Merritt(2010) and Ben-Zvi et al. (1986) and Kokkotas, Vlachos and Koulaidis (1998)**.** 10 students of class XI were part of pilot stage. Responses of students were studied. Open ended interviews were conducted for all 10 students to understand their responses. Questions were changed or re-framed based on the students' responses.

Questions which intended to assess clarity of inter particle distance in different states of matter were re-framed. During interviews it was realized that the problem area is inter-particle distance in liquid state, so questions were re-framed. The changed question tested understanding of particles in liquid state. In another question, student's seemed to understand evaporation as breaking of water molecules away from other water molecules, but clarity of what this 'breaking away' meant was missing. Interviews showed, it was majorly thought as breaking of covalent bond, so this question was re-framed. Diagram showing hydrogen bonds and covalent bonds was given asking about which bond(s) are broken during evaporation.

Question on what lies between particles of matter, many students answered 'nothing', which was the correct option. Interview revealed that students thought amongst the options provided, only nothing fits, which actually means something. Like when we see an empty glass, it has nothing that we can see but it actually has air.

All open ended questions were re-framed after getting an initial feeler of possible gaps in Understanding of Particulate Nature of Matter.

Following the pilot stage, questionnaire was sent to experts for their comments. The questionnaire was vetted by experts Dr Uma Sudhir and Dr Arvind Sardana from Eklavya. The questionnaire was then administered to the sample.

Data Analysis

The data was analysed to draw out the alternative conceptions if any held by the students. 1 mark was allotted for each correct answer and 0 for incorrect answer in MCQ. The open ended question correct answer was awarded 1 mark and correct reason 1 mark. To understand the answers better interviews of students were also conducted.

On analyzing the data, it was found that 50% students assumed solids are immobile. Students associate mobility with particles of liquids and gases as these two states are fluids. Solids are seen as fixed, so the students face difficulty in understanding motion at particulate level.

Nearly 50% students assume distance between particles of liquids is intermediate of solids and gases. The reason that came out on the basis of interviews was the diagrams given in textbooks show space between liquid particles more than solid and less than gas particles.

Particles change in size and melt or boil when state change occurs, is assumed by nearly 45% of the students. Daily experience of comparative densities of solid, liquid and gas is responsible for students' assumption that particles of gas are lighter than liquid while that of solid heavier. On probing further, it was found students do mention that the inter-particle distance changes on state change but macroscopic observation is a barrier to understanding what happens at particle level. Similarly students' understanding that particle of a shiny substance shines, of a grey substance is grey and of a conductor is a good conductor shows bulk properties are properties of the particles too. This was observed in 70% of the responses.

Another alternative conception which was found in 60% of the students was matter is continuous. There is something, maybe air between particles of matter. As when we say the glass has nothing, it means glass has air, said one of the students during the interview.

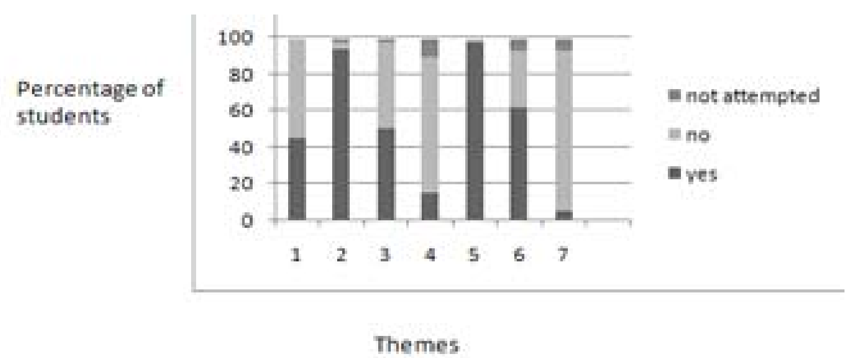

Figure 3: Percentage responses of students on themes 1 to 7 (1: decomposition occurs on boiling, 2:atom conducts electricity 3: atom has colour 4: size of particle changes on state change, 5: overestimation of distance between liquid particles, 6: solid particles are immobile and 7:particles melt.)

CONCLUSION AND IMPLICATIONS

Nearly 50% students who have chosen science stream in class XI are found to have alternative conceptions related to particulate nature of matter. The students have studied the atomic theory in detail in class IX. Also in class X they have studied chemical reactions, periodic classification and types of bonds. The data analysis is a striking revelation about understanding of basic concepts in chemistry. These alternative conceptions will impede their understanding of chemistry at senior school level. Students who associate breaking of covalent bonds with state change actually have little understanding of physical and chemical changes. The idea that size and weight change with change of state will affect their understanding of periodic classification. The overestimation of inter-particle space in liquids is also responsible for the understanding that liquids are compressible to some extent. Inability to appreciate compressibility of gases is due to under estimation of distance between its particles. Poor understanding of evaporation and boiling can be associated with the alternative conception that temperature of a substance is same as temperature of each of its particles and not dependent on its average kinetic energy.

More than 95% students assume atom to have same colour as the substance. From this study, for example, it came out that students assume sulfur atom to be yellow as sulfur is yellow in colour. Making note of alternative conceptions (as represented in figure 2) teachers can plan their lessons in a manner that these conceptions are hit upon. While teaching atomic theory, a teacher can question students about colour of carbon atom. They may reply black as graphite is black. Initiate a debate, why black? Will it be a conductor? Why do you think carbon atom will conduct or not conduct electricity? Let them compare graphite atom to atom of diamond, which is also carbon, and now explain what will be colour of atom, or conductivity. Create a confusing situation and let students resolve the confusion and arrive at scientifically correct conception. Teacher can also weave in historical development in understanding of atom. Starting with initial thoughts that atoms of iron have hooks and that of cheese are cheesy and correlate it to student's idea of atom of carbon being black.

Chemistry teachers often face difficulties in teaching topics like chemical bonding, evaporation, boiling, periodicity of properties of elements to name a few. The cause of these can be traced back to poor understanding of particulate nature of matter. Therefore, it is essential for teachers to be aware of alternative conceptions of students and to find out means to reduce these. Use of historical narratives, computer simulations and philosophical debates are a few methods which can be used to reduce these alternative conceptions.

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BEYOND CONTENT AND SKILLS: MISALIGNED EPISTEMOLOGICAL BELIEFS FOR SCIENCE AND BIOLOGY LEARNING

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This study explores college biology students' epistemological beliefs about science and biology learning using a previously developed tool; the MBEX (Maryland Biology Expectations) survey. The survey was administered in an introductory biology course, at the beginning (pre-) and end of the semester (post-) and differences in students' epistemological beliefs were calculated between post-pre. None of the changes was found to be significant, with a majority of students (61% of n=161) holding the same mismatch of epistemologies throughout the academic semester. Although students' science epistemologies are favourable, they are not aligned with their epistemologies about learning biology when it comes to an introductory biology course. Students seem to bear a group of unfavourable epistemological beliefs relevant to their classroom learning. Development of instructional approaches that could foster the development of student science epistemologies and align them with those about biology learning is necessary in order to advance college biology education.

INTRODUCTION

Although college biology students usually excel in knowing facts about different biological principles, it has been well-documented that they lack critical thinking, experimental hypothesis development, and data interpretation abilities (Barnett & Francis, 2012; Butler et al., 2012; Flores, Matkin, Burbach, Quinn, & Harding, 2012). In addition, the learning goals and assessment items of introductory biology courses have been found to focus more on memorization of facts rather than higher-order cognitive skills (Momsen, Long, Wyse, & Eber-May, 2010).

Several publications have discussed the need to create learning environments where students are supported towards the development of higher-order cognitive skills (American Association for the Advancement of Science, 2011) [AAAS]. Content and procedural knowledge is important for the development of students' scientific skills, however epistemological beliefs may play as important of a role as well (National Research Council, 2012) [NRC].

Epistemological beliefs are an individual's beliefs about the nature of knowledge and nature of knowing (Hofer, 2004; Schommer-Aikins, 2004; Hofer & Pintrich, 1997). Epistemological resources are "smaller in size" than beliefs, providing a finer unit of analysis for research studies on students' epistemologies. An epistemological resource is an individuals' perception of the source of their own knowledge, in other words, the understanding of "how do I know what I know," which is necessary to develop their personal epistemology (Hammer & Elby, 2002; Hofer, 2006). Building on diSessa's knowledge in pieces (diSessa, 1993), epistemological resources can be seen as units of thought, which are context-dependent. This means that when a student's epistemological resources are activated in the right context, they can be productive reasoning tools that students use to understand a phenomenon (Hammer, 2000). In other words, epistemological resources can shape a student's beliefs for scientific knowledge and biology learning. As such, the MBEX (Maryland Biology Expectations Survey) was designed to help educators unravel biology students' epistemologies about science and biology learning and it has been used in large-enrollment introductory courses (Hall, 2013).

There is evidence that the development of epistemology is affected by the characteristics of the learning environment where a learner is situated (Hofer, 2001). However, literature reporting biology students' epistemological beliefs for science and biology learning is scarce. The aim of this study was to investigate the question "What are the introductory biology students' epistemological beliefs at the beginning and end of the semester?" The study was completed in a fast-paced introductory biology class, without any particular class implementation focusing on epistemology. The aim of this study was to measure biology students' beliefs about science and biology learning in class, in order to invite conversations regarding the epistemic climate of large-enrollment introductory biology courses.

METHODS

Participants and course information

Participants of this study were students enrolled in an introductory biology course at a large public R1 institution during the spring semester of 2017. A total of 83% of the student population (n=392) were freshmen and the course is required for biology majors. Some non-majors were also enrolled because they needed to fulfil a requirement for an introductory biology course. The course has three main parts: 3 lectures of 50min. per week, 1 weekly discussion of 75min., and 3h long weekly laboratory sessions.

Maryland Biology Expectations (MBEX) survey

To examine the changes in student's expectations about scientific knowledge and biology learning, the MBEX survey (Hall, 2013) was administered to students at the beginning (pre-) and end (post-) of the semester. The MBEX survey is composed of a total of 32 questions: 24 five-point Likert scale from strongly disagree (1) to strongly agree (5), 3 open-ended questions, and 4 multiple-choice questions. MBEX questions measure student beliefs along four different dimensions/clusters: I) Facts vs. Principles, II) Independence vs. Authority, III) Interdisciplinary Perspectives vs. Silo Maintenance, and IV) Connected vs. Isolated. Clusters I and II included 5 overlapping questions, according to the original survey's structure. Only multiple-choice questions were used in this study.

Data Analysis

Only responses of students who had consented (during the pre-survey) to participate in this study were used for data analysis. Any students with incomplete survey profiles (with >50% missing responses) were removed from the dataset as those who did not complete the post-survey. The final paired dataset was composed of 161 students who had completed both pre- and post-surveys. The number of favourable, neutral, and unfavorable responses were counted for each question and each survey. Favourable responses can be seen either as experts' beliefs or, alternatively, beliefs that the instructors would like their students to have. When a favorable response is associated with the first two Likert choices, then the last two will be associated with the unfavorable response and vice versa. Shifts in student beliefs were calculated by subtracting the pre-scores (favourable, neutral, unfavourable) from the post-scores (favourable, neutral, unfavourable) for each question and for each student. In previous research, it has been found that a shift of 5% in a particular cluster is considered statistically significant (Hall, 2013).

RESULTS

Overall, beliefs of students tended to favourable ones in all four clusters of MBEX survey during an academic semester (Table 1). On average, a majority (pre%, post%) of students believed that scientific knowledge should be independently built (Cluster II, 73%, 70%), interdisciplinary (Cluster III – 58%, 56%), based on principles (Cluster I – 72%, 72%), and connected (Cluster IV – 62%, 58%). However, when a further break down of each MBEX cluster's statements were made, it was seen that these beliefs are opposite from those students have about learning biology, where facts seem to matter more than concepts, knowledge coming from the instructor seems most important, and connections with the real-world or other disciplines can not be easily made. A brief description is given for each MBEX cluster:

Beliefs about Facts vs. Concepts - Cluster I (pre%, post%)
Almost half 53%, 53% (pre%, post%) of the total student population disagreed that "Learning biology is mainly a matter of memorizing the various facts presented", however only 25%, 37% of the students agreed with the statement "I am more interested in general biological principles than the specific facts that demonstrate those principles." Similar results for this question were found by Hall (2013), where the majority of students disagreed with this statement in all the various courses studied. On the other hand, 89%, 88% of students agreed with the belief that learning biology concepts for a test and organizing information should not be done verbatim, but in a self-constructed way, and 71%, 71% of them agreed that their exam performance in biology courses should reflect how well they "apply course material to situations not discussed in class."

Beliefs about Independence vs. Authority – Cluster II (pre%, post%)
73%, 70% of students seemed to prefer independent learning instead of relying on knowledge coming from an authority. However, 40%, 41% of the students agreed that exams should be made of "A large collection of short-answer or multiple-choice questions, each of which covers one specific fact or concept," in contrast to the favourable response "A small number of longer questions and problems, each of which covers several facts and concepts." Regarding organization of biology textbooks, 89%, 88% of students agreed that "A good biology textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each chapter as separate because they're not really separate." In addition, 52%, 39% of students disagreed with the statement "If biology professors gave really clear lectures, then most good students could learn the material without having to spend a lot of time thinking outside of class." This belief shows that learning is associated with studying outside class and that students expect to spend time independently (without an instructor) to complement their classroom experiences.

	Pre-survey (%)			Post-survey (%)			Differences (%)			
Q #	Fav.	Neut.	Unfav.	Fav.	Neut.	Unfav.	Fav.	Neut.	Unfav.	
1	*53	26	21	53	20	27	0	-6	+6	Cluster I
3	86	12	2	84	12	4	-2	0	+2	
6	**25**	**30**	**44**	37	33	30	+12	+3	-14	
16	86	7	6	83	13	4	-3	+6	-2	
20	71	n/a	29	71	n/a	29	0	n/a	0	
21	92	n/a	8	92	n/a	8	0	n/a	0	
22	89	n/a	11	88	n/a	12	-1	n/a	+1	
23	60	n/a	40	59	n/a	41	-1	n/a	+1	
24	89	n/a	11	84	n/a	16	-5	n/a	+5	
Av.	**72**	**19**	**19**	**72**	**19**	**19**	**0**	**0**	**0**	
1	**53**	26	21	53	20	27	0	-6	+6	Cluster II
4	65	26	9	63	16	21	-2	-10	+12	
5	**52**	**27**	21	39	27	34	-13	0	+13	
17	92	6	2	80	9	11	-12	+3	+9	
20	71	n/a	29	71	n/a	29	0	n/a	0	
21	92	n/a	8	92	n/a	8	0	n/a	0	
22	89	n/a	11	88	n/a	12	-1	n/a	+1	
23	60	n/a	**40**	59	n/a	41	-1	n/a	+1	
Av.	**73**	**21**	**19**	**70**	**18**	**23**	**-3**	**-3**	**+4**	
2	46	37	17	42	34	24	-4	-3	+7	Cluster III
8	45	29	26	40	34	27	-5	+5	+1	
12	40	34	**27**	38	38	24	-2	+4	-3	
14	**35**	**40**	25	42	30	28	+7	-10	+3	
18	65	31	4	60	31	9	-5	0	+5	
19	96	4	1	91	6	2	-5	+2	+1	
Av.	**58**	**30**	**15**	**56**	**30**	**17**	**-2**	**0**	**+2**	
7	89	4	6	80	12	9	+9	+8	+3	Cluster IV
10	84	15	1	72	19	9	-12	+4	+8	
11	67	25	8	66	20	14	-1	-5	+6	
13	**22**	**29**	**49**	23	25	52	+1	-4	+3	
15	84	15	1	80	13	7	-4	-2	+6	
Av.	**62**	**20**	**17**	**58**	**19**	**22**	**-4**	**-1**	**+5**	

Table 1: Differences in the percentages of favorable, neutral and unfavorable responses per each question of each cluster of the MBEX survey.

*No decimal places are shown, numbers are rounded up.
Highlighting shows the lowest and highest percentages in each cluster in the pre-survey

Beliefs about Interdisciplinary perspectives vs. Silo maintenance Cluster III (pre%, post%).
Freshmen in this university seemed to recognize the value of learning chemistry along with biology (96-91% agreed for chemistry), but not so for physics (35-42% agreed) and mathematics (46-42% agreed). A high number of neutral responses (ranging between 29%-40%) were seen in this cluster, which may indicate indecisiveness of students over agreeing or disagreeing with a statement about interdisciplinary knowledge coming from a lack of personal interest or expectations. These results are probably not surprising for the introductory biology course population of this study, since there was no overlap between the course's syllabus and physics or mathematics courses. Hall's results on high unfavourable scores (33%) (and 27% neutral), even in reformed interdisciplinary biology courses, may show that a particular learning environment may not be enough to shift student beliefs (Hall, 2013).

Beliefs about Connected vs. Isolated Knowledge – Cluster IV (pre%, post%)
A majority of students (62%, 58%) agreed that knowledge learned in this class can be applied to other situations. Similar findings have been reported on the real-world connection part of the CLASS-Bio survey (Colorado Learning Attitudes about Science Survey), where 65% of majors and 53% of non-majors expressed similar beliefs in the pre-survey (Mollohan, 2015). However, about half of the students (49%, 52%) agreed with the statement "Biology classes should be designed to help students master the factual material for doing well on the MCATs, GREs, and other professional exams." This expectation probably results from the ambition of many introductory biology students to follow professional careers and their high interest in these required performance tests. Along with the agreement with the statement "Biology class should just present all the different facts. Trying to present the unifying theories doesn't really help us understand anything" (86%, 84% - from Cluster I), it is interesting to note that these statements imply fact-based learning having taken place in an introductory biology course.

DISCUSSION

On a per student analysis, this study found that out of total 161 students (paired data), 82 students shifted negatively, 16 did not change their beliefs, and (65) shifted positively (ranging from 1 to 10 out of 24 total responses), using the MBEX survey. Considering each cluster's averages of favourable and unfavourable responses (Table 1), no significant (>5%) shifts were found, however students shifted their beliefs either favourably or unfavourably for specific items of each cluster. It was also noticed that the variety of favourable-unfavourable scores per student was greater in the post-survey, indicating that their beliefs shifted throughout a semester of introductory biology. Hall has previously reported shifts ranging from 0% to 2% for Organismal Biology course, which is similar to the introductory biology course described in this study (Hall, 2013). On the other hand, comparing these findings with the conceptual connections/memorization part of CLASS survey, it was found that the epistemic beliefs of introductory biology students who were majors had largely shifted towards novice-like beliefs (-39.7), however positive shifts (+1.8) were seen for the non-majors. The authors are unsure about the reasons for these shifts (Mollohan, 2015).

What students are invested in learning is affected by what they believe about science. In this study, when students were asked whether "Knowledge in biology consists of many unrelated facts," (#3, Table 1) 86%, 84% (pre%, post %) of them disagreed with this statement, however only 53% disagreed with the statement "Learning biology is mainly a matter of memorizing the various facts presented" (#1, Table 1). The difference between these two questions is that the first one asks about the nature of (scientific) knowledge in general, whereas the second one asks about the environment of learning biology, which students probably relate to their classroom experiences. Memorization of facts may appear more practical or applicable in a fast-pace introductory biology course, even though students recognize that the science of biology is perceived as a coherent network of biological principles. When we informally asked students about how they studied for the final exams, one statement was: "I found I didn't have enough time to make all the connections I wanted to be able to do well in this course but I definitely think it helps."

In pre- and post- surveys respectively, 40% and 41% of students agreed that "a large collection of short-answer or multiple-choice questions, each of which covers one specific fact or concept" (#23, Table 1) is the best way to measure how well students understand the material, positioning them against conceptual understanding. Students seem to understand their role in the classroom as heavily dependent on the instructor and the information that is delivered by them. Some students also described this by saying: "So for the first exam I definitely looked at the discussion quizzes, because I think the professor wrote those, I am not entirely sure [short pause] but the in-lecture activities looked them too, because they were written by him I think." Sandoval has argued that students' practices in class are different from their personal beliefs about science, even in an inquiry-based course. Practical epistemologies are beliefs students have about their own scientific knowledge building in the classroom, whereas formal epistemologies are epistemological beliefs about science that professional scientists have (Sandoval, 2005). Findings from this study are in agreement with Sandoval's work, supporting the statement that learning in classroom may enact a category of epistemologies for science, which we name "classroom epistemologies" and they differ, to various extent, from the formal epistemologies about science, or simply called science epistemologies.

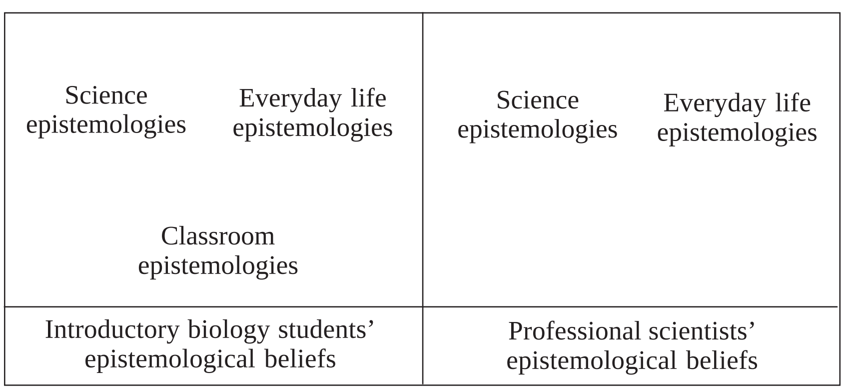

Figure 1. Comparative analogy of probable epistemological beliefs held by introductory biology students versus professional scientists

In this study, an obvious distinction between beliefs about biology learning and beliefs about scientific knowledge was seen in both the pre- and post- surveys. Specifically, we argue there are three main categories of epistemologies that college students might possess (Figure 1). First, they have science epistemologies –

or beliefs about “what real scientists do to produce evidence for a phenomenon.” Second, they have everyday life epistemologies, personal beliefs about knowledge and learning in informal environments, at home, or places outside the classroom. Third, there are classroom epistemologies, beliefs students have about “what do I need to do to succeed in this course.” These findings suggest that beliefs about success in class and beliefs about (biology) science are differentiated in students’ minds and their educators may not be aware of this mismatch.

The instructors of the introductory biology course of this study were heavily interested in students’ conceptual understanding. For this reason, the course exams were very concept-related and much less fact-related. Regardless of the instructors’ efforts in the course exams, and the amount of in-class activities incorporated within lecture time, a lecture-based learning environment may not be appropriate for the development of student science epistemology. Regarding final exam studying methods, students who responded to the follow-up questions recognized that memorization of facts wouldn’t have helped them succeed in this course and a lot of studying time was needed to understand the material. The students talked about drawing on whiteboards, or explaining biological processes/phenomena to their friends, or that they “tried to connect stuff from lecture to lecture.” In particular, one student mentioned: “I combined all the stuff from the circulatory system and the different systems and tried to connect them, so I can make connections in my mind and then I explained it in my own words.” These attitudes are all supporting the belief of connectedness in biological knowledge, however, achieving this in an introductory biology course may not always seem practical in the students’ minds.

Introductory Biology courses should provide students with the epistemological resources necessary to build their favourable beliefs for science and align those to the ones for biology learning. Biology instructors need to be able to measure their students’ epistemic beliefs and adjust their course syllabus according to the results. Unfortunately, this is a rather undeveloped area of research in biology education. We have made a lot of progress in teaching scientific content and lab skills, however, these cannot suffice for scientific skills development, without proper (favourable) epistemological beliefs for science.

CONCLUSION & LIMITATIONS

The findings of this study showed that first-year college students have various beliefs about biology knowledge and biology learning, with the latter heavily related to their classroom experiences. Those expectations, however, do not seem to align with those of their instructors (favourable ones) and they do not seem to shift to more favourable ones by simply introducing active learning in lecture. Because of the misalignment between epistemological beliefs about science and learning biology, students may prioritize their work on meeting the classroom expectations, which negatively impacts their authentic learning early in the beginning of their college education. Given the importance of these epistemologies on student learning, we must consider the question of how educators should introduce content along with professional science epistemology, with the goal of shifting and eliminating students’ classroom epistemologies (Figure 1).

This study was conducted during a single semester with students from one biology course, thus the findings may not be representative of all US college biology students. Although measurements were taken to eliminate unintentional responses, there is always a chance that a percentage of responses may not reflect the true beliefs of students. To the best of our knowledge, no statistical validation of MBEX survey is available, which may be needed before using it in different learning environments than the original one.

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INFORMAL LEARNING ENVIRONMENT TO COMMUNICATE SCIENCE: AN *OPEN DAY* EVENT AT THE INDIAN INSTITUTE OF SCIENCE, BANGALORE

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In the present work, we have discussed the hands-on activities and games performed in an "Open Day" event at the Indian Institute of Science, Bangalore. The participants are students from various academic institutions and the general public. The volunteers are chemistry teachers and educators from various organizations and institutions. In the view of celebrating the international year of the periodic table (IYPT-2019), participants were exposed to three different games which were designed based on the periodic table and Bohr's atomic model. During this event, the volunteers explained the history of the periodic table, the importance of IYPT-2019 and the game rules to the participants. Both the card and board games entertained the players with active participation and also resulted in effortless learning. In order to extend the knowledge about IYPT-2019, all the participants and winners were rewarded with pocket-size cards, charts, and books related to the modern periodic table.

INTRODUCTION

Science communication is emerging as a favored approach for communicating science both in a formal and informal way to the audiences/participants. Effective science communication is crucial to spread scientific thoughts and to develop an interest in science learning especially among young students (Burns, O'Connor, & Stocklmayer, 2003). It has also helped the general public familiarize with the basic principles of science and appreciate the contribution of science to everyday life. During the sixteenth and seventeenth centuries, science communication aimed mainly to engage the audience in wonderment and surprises (Knight, 2002). In late 1700, the Royal Institution was founded, which became the center for spectacular scientific lectures and was very popular among the upper classes of the community. Most popular lectures were delivered by experts like Humphry Davy, Michael Faraday, John Tyndall, and Henry Huxley. Even today, evening lectures and Christmas lectures are delivered to communicate science at the Royal Institution, London. (James, 2002; Austin and Sullivan, 2018). By the twentieth century, science demonstrations moved from learned class to include people from all the strata of society by introducing planetariums, exhibitions, science workshops, and museums to disseminate the ideas of science.

The environment of science learning is broadly classified into two ways, formal and informal learning. The formal learning environment is a traditional lecturing format which is largely present in schools, colleges, and universities. The informal learning environment is non-structural learning which includes a broad array of settings like museums, exhibitions, science shows/demonstrations, theatres, media programs, botanical gardens and other activities to transmit knowledge. A growing literature shows that students learning in a formal setup find science to be a difficult subject (Johnstone, 1991; Reid, 2008). Among the various scientific disciplines, chemistry is largely considered as a tough subject due to the nature of the subject itself. (Taber, 2001; Tumay, 2016; Alsop and Watts, 2003). Certain topics like atomic structure, the periodic table, mole concept, chemical bonding, and chemical equilibrium are considered as threshold concepts for high school students (Johnstone, 2010; Johnstone and Kellett, 1980). A plethora of research shows that using educational games will be fun, interesting, motivating and captures students' attention for a longer duration (Franco-Mariscal, Martínez, & Maìrquez, 2012; Franco-Mariscal, Martinez & Mairquez 2016; Martí-Centelles and Rubio-Magnieto, 2014; Tan and Chee, 2014).

In this paper, we discuss the activities performed in an informal learning environment known as '*Open Day*' event which is organized by the Indian Institute of Science (IISc), Bangalore every year (https://www.iisc.ac.in/events/iisc-open-day-2019/). IISc, a premier research institute opens its doors for the public every year on an open day event and this tradition has been followed since 1956 till date. The aim of this event is to showcase the research undertaken in the institute and to communicate important scientific concepts to the general audience. The year 2019 being the international year of the periodic table (https://www.iypt2019.org/), we had a stall during the open day event (March 23, 2019) to engage students/participants with some chemistry games. These games engage students in an interactive, enjoyable learning environment and also foster conceptual understanding. The activities included card games, board game, and a crossword puzzle which helped participants to realize that the invention of the periodic table is one of the most significant achievements in science. The students from various schools and colleges actively participated in our designed games. In an effort to encourage learning about the periodic table and atomic structure, all the participants and winners were rewarded with different prizes.

METHODS

Understanding the structure of the periodic table gives the ability to make predictions concerning atomic size, ionization energy, electron affinity, electronegativity, melting point, *etc.* about different elements (Rouvray, 2004). About four optimized games based on the periodic table and Bohr's atomic model were introduced to the participants during IISc open day event (Figure 1). The objectives of those games were as follows:

- To recognize the name, symbol, group and period of the elements in the periodic table.
- To recall the chronology of various periodic tables till the modern periodic table.
- To understand the electronic configuration and distribution of electrons in an atom.
- To correlate electronic configuration and the periodic table classification.

Figure 1: Game materials for the participants (a) *ChemDom* - card game (b) *ChemUno* - card game (c) *ChemUdo* - board game and (d) Elements name searching puzzle game

Games rules

The card games such as *ChemDom, ChemUno* were designed based on the periodic table and the board game *ChemUdo* was developed to explain Bohr's atomic model. Both the card and board games were designed to enhance students' engagement and motivation towards the learning goals and not by following any pedagogy. The rules and methods for each game are given below.

(i) *ChemDom:* *ChemDom* is a card game for 2-10 players. There are 118 cards in a deck that corresponds to the elements of the Periodic table. Each card is printed with the symbol, name, electronic configuration, block that it belongs to the periodic table, atomic number, period and group of an element with a *hypothetical* rank. Hypothetical rank is a random number given to each card. It is an independent variable and there is no correlation between other variables mentioned. The objective of this game is to recognize the name of the element, its symbol, electronic configuration, period, group and atomic number. The game begins by equally distributing cards among all the players. The player on the right side of the person who has distributed cards will start the game. The players will look at the above first card and declare one of the five variables (atomic number, period, group, block, and rank) in that round of the game. Subsequently, all the players will be showing their cards. The person with the highest value will be winning that round. However, if the variable is rank, then the participant with the lowest value will be winning that round. The order for blocks is s<p<d<f. All the cards that were displayed will be taken by the winner. The process goes on until one player remains with a maximum number of cards.

(ii) *ChemUdo*: *ChemUdo* is a board game that can be played by a maximum of four players. The Game set includes the mainboard, 36 small display cards, dice, 16 e-cones (pawns) of red, blue, green, and yellow colors. The objective of this game is to understand the Aufbau principle and Pauli's Exclusion Principle. Each player will pick and display a card, which has the name, atomic number and electronic configuration of an element. The participants will choose four e-cones of identical color and the game begins with a person who gets the highest atomic number by rolling dice. Players are required to get either six or one to enter the home (center) for each e-cone. Eventually, the game continues the anti-clockwise direction. E-cone degeneracy will not be allowed in any orbital except s orbital. Each player will be commencing the game to complete the electronic configuration of the chosen element. The player who completes the electronic configuration of all the chosen elements of all participants will be considered as a winner.

(iii) *ChemUno:* *ChemUno* is a card game that is very similar to *the UNO* game for 2-10 players. The objective of this game is to recognize element symbol, atomic number, group, period and general properties of elements. There are 103 cards in the deck. Cards are of four different colors red, blue, green and yellow. There are two types of cards: number cards and action cards. Number card consists of the element name, symbol, atomic number, group and period of an element. Besides the Number cards, there are several other cards that help mix up the game. These are called action cards with five different actions and the descriptions of action cards are given below.

(a) ***Reverse*** – When a player gets a Hg or Br card, the clockwise direction game switches to counterclockwise or vice versa. This is to convey to participants that only Hg and Br elements are in the liquid state at standard temperature. (b) ***Skip*** – When a player places inert gas cards (He, Ne, Ar, Kr, Xe, Rn), the next player has to skip their turn. This will make participants understand that these gases do not react with any other elements. (c) ***Draw Two*** – When a participant discards a semi-precious element (like Ag & Cu) the next person will have to pick up two cards and forfeit his/her turn. From this, the students come to know that these elements are costly but not exorbitant. (d) ***Wild*** – This card represents all four colors, and can be placed on any card. The player has to state which color the card represents for the next player. This rule followed to convey to students that these elements are versatile and they react with most of the elements known. (e) ***Wild Draw Four*** – This acts just like the wild card except that the next player also has to draw four cards as well as forfeit his/her turn. This is to convey to students that these elements are very exorbitant in cost.

After shuffling, 7 cards are distributed to each player and they are dealt face down. The rest of the cards are placed in a draw pile face down. The top card should be placed in the discard pile, and the game begins! The game usually follows an anti-clockwise direction and all the players should try to match the card either by period, group or block (color) in the discard pile. Besides the card and board games, a crossword puzzle (element names) game was created to engage participants who are not familiar with the atomic structure and periodic table properties.

RESULT AND DISCUSSION

Students, parents, and teachers from various schools and colleges attended the "Open Day". Approximately

25,000 - 30,000 people visited the event at IISc. We designed our stall in association with the chemistry department of IISc to engage 40-50 participants in a batch. In the stall, 3 sets of each game were facilitated by 10 volunteers to participants aged above 12 (Figure 2). The role of volunteers is to undertake two major tasks - one of them is to facilitate games, and another is to provide logistics for distributing prizes and participatory gifts to the players. The volunteers introduced all the games to the participants by describing the theme of IYPT-2019, followed by questions pertaining to the periodic table and the atomic structure. The students were allowed to choose games randomly with their peers and also others.

As described in the introduction, game-based learning is a technique to motivate students to learn and understand concepts in an interesting way. The designed card and board games showed positive impact on the students' perceptions towards learning chemistry. Many students expressed their interest to learn all the chemistry concepts through a game-based approach. The participants enjoyed all the activities and some of the students showed competitive behavior while playing games. In comparison to the general public, school students quickly developed an interest in all the games. Initially, the volunteers asked a few basic questions to examine the acquaintance of the participants with the periodic table, periodic properties of elements and its electronic configuration. The common questions asked to all the students during the activities are given below.

- What is the periodic table?
- Are you familiar with IYPT-2019?
- Can you write the electronic configuration of any element?
- What do you know about subatomic particles?
- Do you know how the elements differ in properties?
- Do you know the shapes of s, p, d, and f orbitals?

Figure 2: IISc Open Day activities (a) Participants actively engaged with games, (b) & (c) Volunteers explaining card and board games, (d) Young participants deeply involved in the word puzzle game, (e) pocket size and chart periodic table for the participants, (f) The periodic table handbook for winners

Specific questions were asked to identify the alternate conceptions of the students who enrolled in pre-university and undergraduate courses. The volunteers collected data to test our hypothesis that the majority of the students lack knowledge on certain key facts and/or do not possess conceptual understanding of periodic table and atomic structure. A few example questions are - *"How are the elements arranged (in terms of atomic properties) in the periodic table? Which is the smallest element by size? What is the physical state of bromine at room temperature?"* and so on. For the first question, we observed an erroneous thought among a lot of students that *"elements are arranged in the increasing order of atomic size"* which was rectified by the volunteers. We also observed there exist a confusion between atomic mass and atomic size among students. Therefore some of them are wrongly relating the number of electrons to the atomic radius: *"Hydrogen has the smallest radius because it has only one electron"*. For the second question, some of the students answered wrongly that *"Hydrogen is the smallest element by size"*. Most of the students answered correctly as helium but without any explanation indicating the answer might have been memorized or guessed. Later during the gaming sessions, the facilitators explained the nuclear charge differences between hydrogen and helium to improve their understanding. The common misconception for the third question was, *"Bromine is a gas at room temperature like fluorine and chlorine"*. Playing with '*reverse*' active cards in *ChemUno* game, the players came to know that bromine and mercury are in liquid state at room temperature. It came to our notice that some students erroneously thought, *"there is no relation between the number of electrons and the chemical behavior of an atom"*. Later by the descriptions of active cards in *ChemUno* game, volunteers made clear the relationship between the outermost electrons and the chemical properties of some elements. By playing *ChemDom* card game, the students got familiar with the Greek names of the elements. From the students' response which were collected after the gaming sessions, we imply that the constant playing of both *ChemUno* and *ChemDom* card games will help in identifying group, period, atomic number and properties of most of the elements. The *ChemUdo* was identified as the most interesting game among students. Many students expressed that they could identify most of the modern atomic theory concepts in the board game. With *ChemUdo* game, the volunteers explained the application of electronic configuration in determining the period and group of the element without looking at the periodic table. The students asked some significant questions like: "*What is the difference between orbit and orbital?, What is the importance of electronic configuration?, How to write electronic configuration for cations and anions?, What is an unpaired electron?*", and so on. Based on the questions asked by the students, the volunteers explained Pauli's exclusion principle, Hund's rule and Aufbau principle to enable them to play the game. Furthermore, the anomalous electronic configurations of some transition elements such as molybdenum, copper, palladium were also informed during the board game session. It was observed that *ChemUdo* board game aid students to write electronic configuration of elements and improves conceptual understanding of atomic structure. The common students' misconceptions about the periodic table and atomic structure are listed in Table 1.

The main instrument used to evaluate the effectiveness of the games was a survey. After completion of each game, the volunteers interacted with the participants to get feedback about the games and effectiveness in learning concepts. Survey statements from the students were categorized based on their perceptions: the benefits of playing games for learning chemistry, the difficulty or simplicity of the game rules, and their motivation level in participation. Most of the students reflected with positive statements like: *"It is useful to learn effortlessly"*, *"These games support me to learn about less familiar elements"*, *"I like to learn all*

No.	Questions asked	Sample Responses (Verbatim)
1	How the elements are arranged in the periodic table? (in terms of atomic properties)	- *Based on its atomic size.* - *Arranged by atomic weight.* - *Based on its chemical behaviour.*
2	Which is the smallest element by size?	- *Hydrogen atom is the smallest because it has only one electron.*
3	What is the physical state of bromine at room temperature?	- *Bromine is a gas.* - *Gas like fluorine and chlorine.*
4	Is there is any element which don't follow Aufbau principle?	- *All elements follow Aufbau principle.* - *Yes. Radioactive elements don't follow.*
5	What is the correct electronic configuration for Na^{2+} (Z=11)?	- $1s^2 2s^2 2p^6 3s^1$ - $1s^2 2s^2 2p^4 3s^1$
6	Do all the elements have electrons, protons and neutrons?	- *Yes. All elements are made up of three sub-atomic particles.*

Table 1: Students' misconceptions about periodic table and atomic structure

the chemistry concepts through games", "I would like to purchase the game kits to play at home" etc. Some students felt difficulty in following the rules of *ChemUdo* game due to lack of coherent understanding of Aufbau principle, Pauli's exclusion principle, Hund's rule and the difference between orbit and orbitals. Later it was resolved by clarifying all the doubts during the gaming sessions. We observed that the designed games helped the students to overcome their misconceptions. To encourage more participation, pocket-size cards/ posters of the periodic table were issued to all the players (Figure 2). The winners of each game were appreciated with "*The Periodic Table Handbook*" written by Prof. C.N.R. Rao and Indumati Rao. Many teachers and parents responded positively about the gaming sessions and also inquired the availability of game sets to purchase. Some teachers commented that this was their first experience of using games to teach chemistry concepts. By viewing the responses from the parents and the teachers, we suggested that similar educational games can be used in a formal learning environment. However, the teacher needs to understand the objective of the games thoroughly and be able to achieve the required learning goals. We emphasize that there is a strong need for creative educational games like *ChemDom*, *ChemUno*, and *ChemUdo* in formal learning environment because it can be used to monitor the learning process of the students constantly. We also recommend that these games can be used in similar informal learning environments like science exhibitions, workshops, and other science community gatherings with appropriate audience.

CONCLUSION

Informal learning is a great approach to motivate students towards the learning process. All the participants enjoyed the autonomy associated with the IISc-open day event. The activities conducted by us as a part of the Open Day event helped school students to gather knowledge about IYPT-2019 and its importance. Many curious individuals showed deep involvement in solving puzzles, playing games and engaged in constructive interaction with the volunteers. The games and interactions allowed the facilitators to clarify certain common misconceptions in chemistry. This informal learning environment using games facilitates engagement in science learning and also enhances the academic performance of students. The entire program was successfully carried out to communicate science to all learners. There is a plenty of scope to conduct research on informal learning approaches and also incorporating game based pedagogies for various chemistry concepts.

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A STUDENT-CENTRIC APPROACH FOR DEVELOPING SCIENTIFIC COMMUNICATION SKILLS IN UNDERGRADUATE MICROBIOLOGY STUDENTS

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Scientific Communication is an important skill which needs to be developed in students for building a successful career in science. Here, we report the design and development of a student-centric, activity-based course in scientific communication skills (SCS) for undergraduate Microbiology students. We followed a pedagogical strategy that allowed for integration of assessment with the learning activities. The effectiveness of the course was measured by administering questionnaires to the students both before and after the course. The comparison between the results of the pre- and post-intervention questionnaires revealed that the students demonstrated an overall increase in their understanding of key concepts essential for SCS after undertaking the course. This report, even though preliminary, highlights the importance of developing a student-centric course in SCS at the undergraduate level.

INTRODUCTION

Proficiency in scientific communication is an important goal of undergraduate science education. As tertiary level science degree programs form the foundation of the life sciences sector by providing skilled manpower, it has been proposed that formal communication in science courses be introduced at this early stage of career development (Anderson & Helms, 2001; Spektor-Levy, Eylon, & Scherz, 2009). The major aim of such courses is to enable students to develop an ability to locate and retrieve relevant information, to critically evaluate information; to analyse and organize the information; to draw inferences based on evidence; and to be able to disseminate the acquired knowledge in an appropriate form by different modes of communication (NRC, 2012; McComas, 2014). Besides, a course in Scientific Communication Skills (SCS) may also assist students to verbalize their understanding of a subject matter for themselves and self-evaluate their own learning (Murray & Hughes, 2008). However, it has been observed that STEM students often find communicating 'science' a challenging task and traditional courses fail to build the necessary skills required (Grant, Liu, & Gardella, 2015). Therefore, it is essential to develop a course which integrates learning activities incorporated with tasks that aid in understanding the concepts and terms of the subject matter, and at the same time, engage the student in acquiring skills required for communicating their learning (Hurd, 2000). In this regard, an SCS course was introduced to second-year undergraduate science students of St. Xavier's College (Autonomous), Mumbai University in June 2011. Initially, a semester-long, one credit (15 contact hour) course was developed as a series of hands-on activities purposefully designed for better conceptual understanding of the subject matter. The core syllabus of the SCS module offered in the third semester almost remained the same, however, the pedagogy was modified to be more student centric and activity based. The instructors noticed that just the theory of SCS was not enough for the students to understand and apply the concepts of SCS. Thus, the SCS course module was modified and extended to Semester 4 where the students were asked to apply the skills in writing their laboratory projects (proposal, poster, project report, manuscript and presentation) which is evaluated as a part of SCS course.

Here, we elaborate upon the course design and its impact on students evaluated by a questionnaire administered to the students both before and after the first half of the course. We also note the qualitative differences observed in the students' responses and how it has served as a feedback for evolving and improving the course over the last seven years.

METHODS

Course Design and Execution

The SCS course in Microbiology has been divided into six modules spanning over two semesters. While the focus of the earlier semester (third) is the comprehension of various aspects of scientific communication, the latter semester (fourth) deals with the application of the concepts learned.

The first module of the course requires that the students create mind maps on any Microbiology topic chosen by them (in consultation with the mentors) and convert it into a chart or a model to be presented in the annual exhibition organized for the orientation of the first-year Bachelor of Science students. One example of a mind map and the corresponding chart prepared by the student is shown in Figure 1 (Matthews & Matthews, 2008; Buzan & Buzan, 1993).

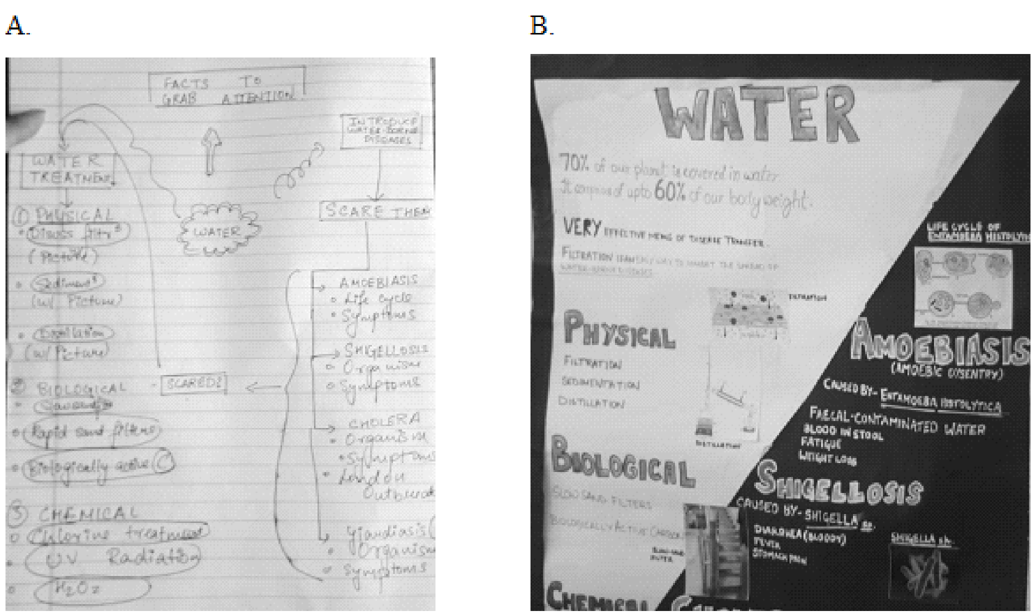

Figure 1: A) An example of a mind map prepared by a student B) shows the corresponding chart made by the same student.

This activity engages the students in researching the literature, retrieving the relevant information, organizing the information and finally verbalizing their assimilated knowledge. The effectiveness of mind maps in organizing information and developing knowledge structures has been established earlier (Buzan & Buzan, 1993) . The evaluation of this task is done by mentors who visit each exhibit (chart/model) and assess it for the relevance of content, comprehensiveness, and clarity. The students are also assessed for their verbal explanation of the chosen topic to the visitors/mentors. We have observed that not only does this task act as an ice breaker between the freshers and the sophomore students but it also develops a sense of self-efficacy among the second-year students.

The next module deals with comprehending technical information and summarizing it. The students are first sensitized to crucial elements of summary writing and then given short research articles or popular science commentaries (audio-visual) relevant to the discipline to summarize in their own words (word limit: 150). It has been reported that summarizing in their own words helps students in comprehension of new information which is an indicator of student learning (Haystead and Marzano, 2009). The difference between a summary and an abstract is also emphasized. The evaluation involves summarizing scientific information provided to students in the form of an audio-visual documentary or a science topic-based film. The use of varied modes of scientific information challenges the students with multisensory inputs and fosters comprehension skills that promote learning (Blomert & Froyen, 2010; Clark, Nguyen, & Sweller, 2006).

The next three modules were designed based on our observation that undergraduate students often struggle with understanding research articles and find it challenging to grasp technical information. Similar difficulties faced by students globally have also been reported (Goldbort, 2006). Proficiency in scientific communication necessarily requires understanding the elements of a good scientific report/research articles. Hence, students are initially introduced to components of a scientific write-up, generally a research article (Murray & Hughes, 2008). One of the most important aspects discussed in detail is ‘plagiarism’. Students’ difficulty with recognizing and understanding the concept of plagiarism is a challenge faced by educators worldwide (Dawson & Overfield, 2006). The concept was dealt with as a series of discussions with exemplars of plagiarism, paraphrasing, and citations extracted from several kinds of scientific literature. Students are also made aware of software available for detection of plagiarism (eg: Turnitin and a free tool available online-SEO plagiarism checker). The idea is to sensitize students to the importance of maintaining academic integrity and avoiding plagiarism. Further, the students are introduced to various sections of a primary research article and familiarized with the IMRaD format (Sollaci & Pereira, 2004). Students are then engaged in a group reading exercise where they try to understand a simple research paper by paying attention to its title, abstract and other sections up to the references as per the standard guidelines (Hoogenboom & Manske, 2012). Generally, the instructors ensure to give research articles from different peer-reviewed journals to familiarize the students to the fact that different journals may follow slightly different formats. This is followed by a discussion of the papers read (2-3 papers) in the class by the groups to share their perspectives with their peers. The papers assigned to the class are usually chosen from the field of Microbiology and mostly have methodologies familiar to students. The final learning task of the course in this semester is critiquing a research paper which is carried out as a group discussion activity moderated by the instructor. The students are divided into groups of 10-12 students and allowed to read and discuss 2-3 papers. This interpersonal exchange of ideas encourages peer learning, teamwork and developing soft skills of a student (Besley & Tanner, 2011). Students are also introduced to allied concepts such as peer review, open access articles and bibliometric databases such as Web of Science and Scopus. The final evaluation for this course involves writing a critical review of a research paper from a journal for them to understand the importance of publishing in peer-reviewed journals. All the aspects learned throughout the semester are assessed in this activity such as students' attention to the relevance of the title, comprehensiveness of the abstract, appropriate literature citations, checking for plagiarism and referencing style. The advanced part of this course is dealt with as an integrated activity with the disciplinary research projects undertaken by students in the next semester (fourth). The students are introduced to literature reviews, referencing styles, reading different types of research reports and other activities. The students write their own project proposals before embarking upon the research projects which are ratified by the mentors. The learnings from both the semesters culminate in the form of a scientific report, a poster and an oral presentation for summarizing their work which forms a part of an assessment for the SCS course.

Participants

The SCS course typically accommodates 33-37 student participants for this study, per year. The students belong to the second year of Bachelor of Science course in Microbiology with an average age of 19 years. The course spans 2 semesters of the year. The number of credits is one per semester and the number of contact hours is 15 per semester.

Questionnaire Design

The course in SCS started in 2011. Although the need for an SCS course was apparent, we began to ponder over the effectiveness of the course after a few years of its inception. We took oral/written feedback from the students to assess the efficacy of the course. In order to formalize the assessment, a questionnaire was designed to evaluate the impact of the course on the students during the last year. The questionnaire was designed based on the modules and what the students are expected to know after the course was completed. Since most students joining the course come with little prior knowledge or familiarity with the topic, the questionnaire comprised of questions about general aspects of scientific communication and was administered to students before the beginning of the course (before the third semester designated as pre-intervention questionnaire) to gauge a baseline understanding of the students for the topic. The students are given 30 min for answering the questions. The questionnaire was also administered at the end of Semester 3 (after the end of the first half of the course designated as post-intervention questionnaire). Over the years, the questionnaire has evolved based on the responses of the students. A sample of the common questionnaire used in the study is given in Table 1.

The questions were purposefully designed to be open-ended in nature to serve as a formative assessment and provide an insight into alternative conceptions of the students. As detailed earlier, in the third semester, the students are exposed to activities for comprehending various aspects of scientific communication while in the fourth semester, they apply all their learning to write a research report. Therefore, a similar questionnaire is administered again to the students at the end of the fourth semester to assess whether the reiteration of concepts leads to the enhanced grasping of the topics. However, in this report, we only present examples from student responses from the questionnaire administered before and after the third semester.

Sr. No.	Question	Responses – Pre- intervention questionnaire	Responses – Post- intervention questionnaire
Q.1	Give an example of plagiarism. You may create one.	• Copy-pasting matter from the internet • Using research material without permission from the publisher • Don’t know • Stealing someone’s idea • Violating copyright	• When a researcher copy-pastes some writing from another paper • When something is written as it is without paraphrasing • A research paper published in one country has the same publication in another country in a different journal • Copying the same words
Q.2	What do you understand by paraphrasing? Explain with the example you have given as an answer to Q.1.	• To explain in one’s own work • Summarising someone’s work • Don’t know • To reduce the size of a big paragraph • Gives credit to the inventor	• Modification of a sentence so that the meaning remains the same • Write a sentence in one’s own words after understanding the essence of the given content • Understand the meaning and then write in one’s own words • Rewriting in one’s own words without the meaning being lost
Q.3	How would you differentiate between a review article and a research paper?	• A research paper talks about one's discoveries, whereas, review article you critique someone's paper • A research paper is writing about the experiment, whereas, a review article is one's opinion of a research article • Don’t know • A research paper is scientifically proven, whereas, a review article is theoretical	• A review article is to critique a paper; research paper gives details • A review is like a summary of many research papers put together; research paper follows the IMRaD format • A review article is not in much detail; research paper gives all details • Review article does not follow IMRaD format; research paper does
Q.4	How is a summary different from an abstract?	• A summary is a scientific content; abstract is something which is thought by a person • A summary is a detailed explanation; abstract is a short mind map • A summary is a whole story or idea explained in short; abstract is all important points about the idea • A summary is something written in brief; abstract is a visual summary	• A summary is an overview of an experiment, abstract gives an idea of the paper • A summary can be written for an article, an abstract is written only for research papers • A summary is a discussion of the article in short. Abstract highlights the main points of the research paper • A summary is a shorthand version of a full-length article or paper; abstract is like a brief preview of the research paper
Q.5	If you were to write a reference for your research paper, how would you write it? Show this as an example of a reference.	• Don’t know • Paper on ABC by Mr. X pgs- 1-2 • Not relevant • Write the page and article number and name of the paper	• Authors, XYZ, journal name • XYZ, authors, journal name • Authors, journal name, XYZ • Author surname, initials, year

Sr. No.	Question	Responses – Pre- intervention questionnaire	Responses – Post- intervention questionnaire
Q.6	Write down the subtitles you would use to write a proposal.	• Don't know • I did not understand • Not applicable • Theory abstract result conclusion	• Introduction, materials, and methods; applications, expected results • Introduction, materials, and methods; applications, expected results, the relevance of the project, budget • Introduction, materials, and methods; applications, expected results, budget, references

Table 1: Questionnaire with examples of pre-intervention and post-intervention Responses

Data Analysis

The responses obtained from the administration of the questionnaire was assessed qualitatively as well as quantitatively. The correct responses were designated as positive responses and the comparative data between the pre- and post-intervention questionnaire is presented as a bar chart (Figure 2). Further, a qualitative analysis was done of the student responses received both before and after the course which served as indicators of a change in student responses. Some randomly chosen responses from both the pre- and post-intervention questionnaire have been presented in Table 1.

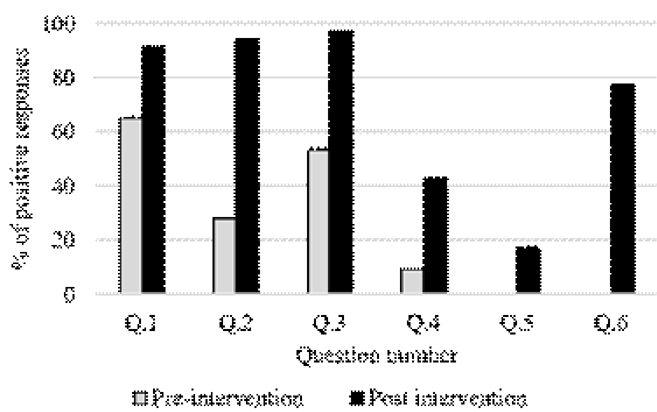

Figure 2: The percentage of positive responses obtained from the students for the administered questionnaire before (pre-intervention) and after (post-intervention) the course is represented on the Y-axis while the number of the question is represented on the X-axis.

RESULTS AND DISCUSSION

The percentage of positive responses obtained by administration of the pre- and the post-intervention questionnaires to students is presented in Figure 2. An overall increase in the number of positive responses was observed across all the six questions. The maximum increase (77.14%) was observed for question number 6 while the lowest change (17.14%) was recorded for question number 5. It was noted that even though students were aware of the concept of plagiarism (Q.1), they did not know about paraphrasing (Q.2).

Most students associated paraphrasing with either shortening the length of the content, summarising the content or writing the same content but giving credit to the original author (Table 1). However, after the course, most students correctly stated the meaning of paraphrasing as writing the content in one's own words after understanding the essence of the original text. This aspect was dealt in the class with several examples of paraphrasing and extended discussions. Based on the formative assessments and feedbacks over the years, it was realized that merely apprising students about plagiarism did not help them in correcting their mistakes while active group discussions in class with varied examples remedied the problem. This was also evident in the examples created by the students as a response to Q.1. Almost none of the students could create an example for Q.1 in the pre-intervention questionnaire. Many did so in the post-intervention questionnaire. An example given by one of the students was "Plaque assay is much similar to viable count" stated as is as plagiarism and modified as "There are various similarities in viable count and plaque assay" for paraphrasing in Q.2. Another example given for Q.1 was "The cellulose degraders were isolated from soil samples and were enriched in MacBeth's medium" and modified as "Soil sample was used to isolate cellulase enzyme producers. MacBeth's broth was used to enrich them." for Q.2.Further, it was observed that students had minimal or no understanding of research articles in general. Most students did not understand the difference between a research and a review article (Q.3) or between an abstract and a summary (Q.4). Most students associated an abstract with a research article only after the course. Students also had minimal or no understanding of the concepts of reference writing before the course which increased marginally after the course (Q.5) (Table 1). However, it was noted that reference writing skills improved substantially after the fourth-semester course where the topic was dealt in much detail and they actually applied it to write the references in their project reports (data not shared in this report). Overall, a change in the vocabulary of the answers was observed where students' usage of technical terms increased in the responses after the course. The activity on critiquing of the primary journal article used for evaluation of module 6 of the course gave an insight into the learning of the students. A few students understood the abstract as something of a prelude to a journal article which does not necessarily outline results. Also, many students critiqued the absence of a detailed method for standard protocols which are generally cited as previous publications in most research articles. Additionally, most students only wrote about the negative aspects of the given article; although we did expect the students to appreciate the well-written portions of the articles too. Most of these issues are discussed with students in the next semester, though we also plan to address these with the next batch of incoming students in the third semester. Since, the students were not exposed to any course on scientific communication skills in their previous years of study, the changes observed in the students' understanding of the subject matter may be attributed to the SCS course module attended in the college.

LIMITATIONS OF THE STUDY

We recognized a lack of general communication skills in English in a few students which made it difficult for us to evaluate their understanding properly. Even though we realize that proficiency in English is a primary requirement for developing effective SCS, currently our course does not address the problem.

We started the course on SCS in the year 2011 with some modules which were activity-based. Every year we observed students, took their feedback and went on revising the course. It has been our observation that student learning improved as we went on designing activity-based classes. Even though we took feedback of the course every year both during the course and at the end of the course, we did not systematically record the student learning data over the early few years. The data that we present in this study is derived from the last year only. There is no quasi control for this study where a similar course without following activity-based methods was delivered and could be used for comparison. However, an elaborate study with an appropriate control group of students and using standard tools for measuring student learning as a proof of concept is now underway for the current year. The data presented in this report is preliminary and is part of the current ongoing study.

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DESIGNING COMPUTATIONAL MODELS AS EMERGENT SYSTEMS MICROWORLDS TO SUPPORT LEARNING OF SCIENTIFIC INQUIRY

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Emergent Systems Microworlds (ESMs) are a special kind of computational models. Design of ESMs involves a combination of two approaches in Learning Sciences, namely agent-based modelling of complex systems and constructionism. ESMs and ESM-based curricula are frameworks for designing learning environments to foster the learning of complex scientific phenomena by engaging students in authentic scientific inquiry practices. In this paper, we discuss our approach in the context of an ESM called GenEvo that we designed for the learning of molecular genetics and evolution. We further discuss how agent-based representations and constructionist design principles mediated students' expansive learning, as students collaboratively constructed knowledge by engaging in authentic scientific inquiry practices.

INTRODUCTION

The goal of science education should not be limited to 'knowing about science', rather it should include 'learning to use science practices and tools to make sense of the world' (Duschl, 2008; Schwarz, Passmore & Reiser, 2017). Such learning would entail epistemologically meaningful engagement in science practices for sense-making, rather than merely knowing about scientific inquiry (Lehrer & Schauble, 2006; Berland et al., 2015). In other words, students should learn to construct knowledge about the world, just like scientists do. In order to support such learning in classrooms, researchers and educators are increasingly designing newer technology-enhanced collaborative learning environments and curricula that are authentic to contemporary scientific inquiry practices and provide epistemic and conceptual scaffolds for learning those practices (Chinn & Malhotra, 2002; Quintana et al., 2004). We contribute to this work of designing for computer-based collaborative science learning by combining two powerful design approaches in learning sciences: agent-based modelling of complex systems and constructionism (Wilensky & Resnick, 1999; Jacobson & Wilensky, 2006; Blikstein & Wilensky, 2010; Wagh, Cook Whitt & Wilensky, 2017). We call this design approach Emergent Systems Microworlds (ESM) (Dabholkar, Anton & Wilensky, 2018).

In this paper, we discuss an ESM about genetics and evolution, and an ESM-based curriculum that has been specifically designed to foster students' learning of scientific inquiry practices. We use Cultural Historical Activity Theory (CHAT) to analyse ESM-mediated expansive learning of science (Engeström, 2001). This is a design-based implementation research paper, in which we discuss design features of ESMs and an ESM-based curriculum, and present empirical support for the claims regarding how these features foster learning of disciplinary ideas and scientific inquiry practices.

THEORETICAL FRAMEWORK

Emergent systems microworlds

ESMs are agent-based models of emergent systems that are designed as microworlds to support students' learning through explorations and investigations of those models.

Emergent complex systems perspective involves understanding how simple interactions between autonomous elements can result in complex emergent patterns at the system level (Jacobson & Wilensky, 2006). This perspective has become a focus of real-world scientific investigations as well as recent science education reforms (Yoon, Goh & Park, 2018). Researchers of science education have argued for and demonstrated the effectiveness of emergent systems perspective for understanding natural phenomena (Wilensky & Jacobson, 2015; Wilensky & Reisman, 2006; Hmelo-Silver & Azevedo, 2006). Next Generation Science Standards in the United States has incorporated 'systems and systems models' as one of the seven key crosscutting concepts (NGSS Lead States, 2013).

Agent-based modelling of emergent systems is one of the central design features of an ESM. Such dynamic computational agent-based representations are restructurations of emergent phenomena which are typically taught with differential equations or static models (Wilensky & Papert, 2010). The agent-based restructurations have been demonstrated to be pedagogically effective to support learning of several complex natural phenomena in science education (e.g. electric current, resistance, temperature, pressure, evolution) (Sengupta & Wilensky, 2011; Levy & Wilensky, 2009; Wagh et al, 2017). The agent-based modelling approach allows students to observe behaviours of agents, and reason about emergent patterns by reducing cognitive and perceptual limitations (Goldstone & Wilensky, 2008).

The Microworlds part of an ESM is inspired by constructionist design principles (Papert, 1980). We use the 'functional' definition of microworlds as being encapsulated open-ended computational exploratory environments in which a set of concepts can be explored, through interactions that lead to knowledge construction (Edwards, 1995). A learner is expected to manipulate objects and execute specific operations instantiated in a microworld. Such manipulations would result in observable changes in the microworld. As learners observe those changes, they receive feedback through representations linked with the objects about their behaviours and changes in the system. Learners use this feedback to induce or discover the properties and functioning of the system as a whole. Through this process, they learn by self-correcting or 'debugging' their understanding of the domain to develop new powerful ideas (Papert, 1980). Constructionist learning environments in the form of microworlds have been demonstrated to be effective for learning in several contexts (Kafai & Resnick, 2012; Noss & Hoyles, 2017).

ESM-based curricula

In an ESM-based curriculum, students explore and learn about scientific phenomena using ESMs. ESM-based curricula engage students in actively constructing knowledge in a computational microworld using scientific inquiry practices similar to those scientists use to construct knowledge about the real world. The computational microworlds are designed on the basis of current fundamental scientific paradigms (Kuhn, 2012). Every agent-level entity in the microworld follows the rules that are specified according to the current scientific principles. Also, emergent patterns are consistent with scientific understanding.

GenEvo – An ESM-based curriculum

The GenEvo curriculum incorporates a series of computational models designed using NetLogo (Dabholkar & Wilensky, 2016). NetLogo is an agent-based modelling software that has been used for research work regarding emergent systems as well as to design educational curricular units (Wilensky, 1999).

Figure 1: A student exploring intracellular molecular interactions in an ESM of a bacterial cell

In this curriculum, students are first presented with a computational model of a bacterial cell with a genetic circuit in which certain components such as proteins and parts of DNA interact in a specific manner. Students explore and play with the model to figure out these interactions and how they result in complex emergent behaviour at the cellular level. In the next two subunits, students explore and tinker with the models of genetic drift and natural selection. They observe competition between cells and reason about emergent patterns at the population level. Finally, students revisit the first model and engineer the genetic circuit to make their cells ‘fitter’ to reproduce. The cells where genetic circuits are designed by the students then ‘compete for survival’ in a limited resource environment.

All of the computational models in the GenEvo curriculum are designed using the agent-based perspective of modelling emergent systems. In each model, the agents and their behaviours at the micro-level are computationally coded. As agents interact with each other and with their environment, it results in emergent patterns at the macro-level (Wilensky & Resnick, 1999; Wilensky, 1999b). Students can observe both the interactions at the agent-level and patterns at the system-level. In this curricular unit, the emergent properties of biological systems include genetic regulation, carrying capacity, genetic drift and natural selection. Students work in small groups of two or three. Their explorations are scaffolded by guiding them to focus on specific aspects of agent behaviours, such as resource availability or DNA-proteins interactions. Students are asked to explore a model and identify its aspect that they find interesting to investigate. They are asked to state it as a research question and state their preliminary answer as a testable hypothesis. Then they design and conduct computational experiments in the ESM learning environment to test their hypotheses and present their investigations. Their findings collectively build towards ideas about the emergent properties regarding genetic regulation and evolution.

ESM-mediated Expansive Learning

We view ESM-mediated students' learning as expansive learning to understand the affordances of ESM-based curricula for mediating students' engagement with disciplinary ideas in the classroom community (Engeström, 2001) (Figure 2). Expansive learning is viewed in the context of an activity system, which includes tool and sign that mediate the relationship between a subject and an object, rules, community and division of labour (Figure 2a). Expansive learning produces culturally new patterns of activity.

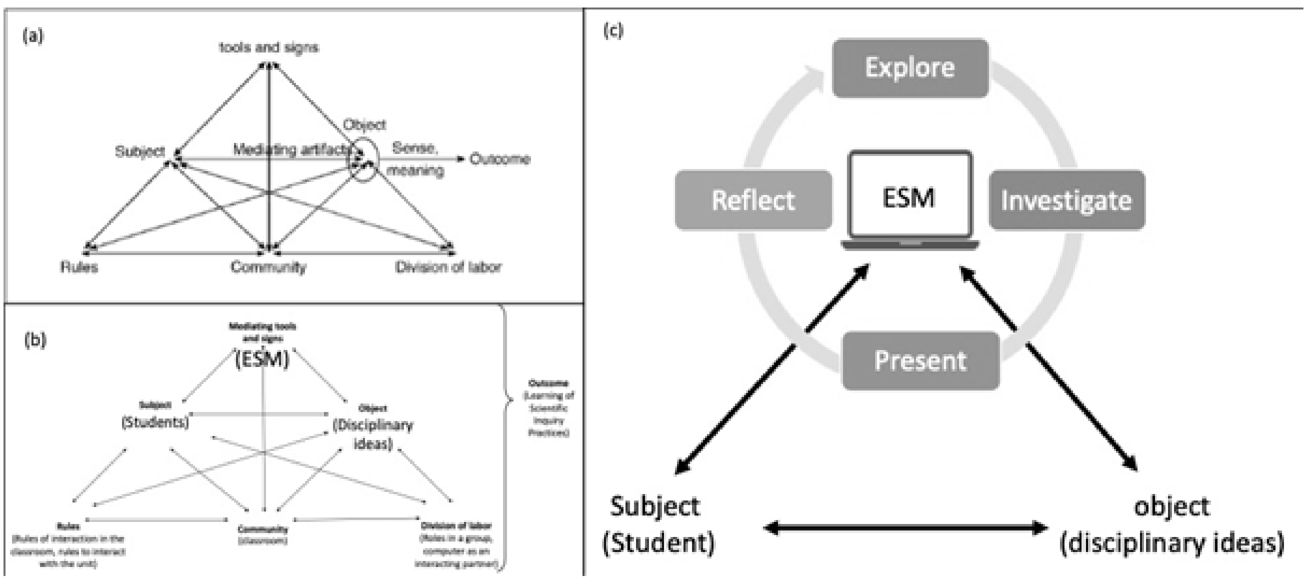

Figure 2: An ESM-mediated activity system (a) A second generation activity system that takes into account learning in the context of a community (Engeström, 2001) (b) ESM-mediation in an activity system in a classroom context (c) Various forms of student engagement with ESM.

In most classroom settings, the relation between the subjects (students) and the objects (disciplinary ideas) is viewed as students understanding the scientific knowledge that is provided to them by teachers and textbooks. Whereas, we expect that a computer-based ESM can potentially mediate students' expansive learning such that it would transform their relationship with disciplinary ideas. Our research question is as follows:

> *How does the design of ESM-based curricula mediate transformation of the relationship between the students and disciplinary ideas as they collaboratively construct knowledge?*

METHODS

Research context

The data used in this paper is from a computational biology course that included the GenEvo curriculum. The first author of this paper was the lead-designer of the ESM and the curricular unit, and the lead-facilitator in these implementations. We use the data from the fourth iteration of the course. The first two iterations were in a weekend extra-school program for middle school students conducted by a talent-development centre in a mid-western university in the United States. The latter two implementations were in residential summer camps in a western city in India where students from all over India participated. The students that participated in both these programs were of age 11 to 14. In the fourth iteration of this design-based implementation research, 12 students participated of whom 5 were females, and 7 were males. All the students were of Asian Indian origin.

Data collection and analysis

We collected data in various forms, namely, extensive field notes by a field researcher in the class, videos of student discussions, workbooks in which students wrote their observations and explanations, the computational artefacts (models, screenshots and presentations). We also conducted pre- and post-tests, and pre- and post-interviews about their ideas regarding science learning and what scientists do. In the sections that follow, we use video data and data from pre- and post- interviews. We focus on interview questions that are about students' perceptions regarding the learning of science, especially from the perspective of understanding their agency in knowledge construction, and practices that scientists follow to construct knowledge. The question prompts were: *(1) Choose any topic that you learned in your science class/ in this course and explain how you learned it; (2) What do you think scientists do as their daily work?; (3) So, scientists construct knowledge about the world, right? How do they do that? How do they know that what they have figured out is right?* We used mixed-methods analysis to investigate how students talk about science learning and practices of scientists. The bottom-up, open coding was done using the constant comparative method (Glasser & Strauss, 2017). All the student responses were then coded by two researchers. Each student response was coded once for every category. The disagreements between the researchers were discussed and resolved until Cohen's Kappa value was greater than 0.7 for each category.

ANALYSIS

ESM-mediated expansive learning

In this section, we share our findings about how certain design features of ESM, specifically agent-based representations and constructionist design in the form of a microworld, fostered students collaborative expansive learning in a classroom context. In the GenEvo course, students worked in small groups. Each group constructed their contextual knowledge through their own investigations in the context of the ESM (Figure 2c). They identified their research questions, designed and performed experiments, and collected evidence. They presented their findings to the class. Other groups in the class questioned them, to seek clarifications and to provide counter-evidence that they may have found through their own investigations. Students iteratively went through this cycle of exploration, investigation, presentation and reflection (Figure 2c). Students were asked to give credit to other groups if they wanted to build on the ideas that were proposed and investigated by other groups. This is similar to how a scientific community cites works of other research groups to build collective knowledge.

Agent-based representations

An ESM provides agent-based representations to reason about emergent patterns in the case of a natural phenomenon. Such restructurations of emergent phenomena with dynamic computational representations improve the learnability of these complex ideas (Wilensky & Papert, 2010). The simplicity of these behavioural representations mediated students' sharing of ideas and allowed them to collaboratively figure out mechanisms of emergent patterns. When Vidya (pseudonym[1]), a rising 8th-grade student in India, was asked how she learned in the GenEvo course, she responded as follow:

> "(I learned) the cell's way of regulating production of specific proteins that are needed because they eat up some energy. Because every protein has its cost, so a cell has to know when it is necessary to make it and not just make it when it's not needed….. Because, it also degrades, so it's of no use….. So, the cell's way of doing that is to produce LacI, which is.... when there is no lactose, it can join with the DNA and it can prevent the formation of LacY and LacZ by RNAP, but when there is lactose, it is unable to do so, because it is blocked by the presence of lactose. (I learned it) by piecing something together. It just came to me, I guess! Before that we were discussing, the LacI and lactose binding thing…. I was wondering why this happened. And then *Sajid* (her partner) found out that when LacI is bound, the RNAP doesn't roll. Then I just thought of it." (Vidya's interview, May 2018)

What Vidya explained is how she learned an advanced emergent phenomenon of molecular genetic regulation. She did this by observing interactions of DNA and proteins as computational agents in the model by herself and building off of her partner's ideas. What Vidya is describing as *'the cell's way'* is an emergent phenomenon that manifests at the cellular-level because of biochemically constrained stochastic molecular interactions. In the conversation above, Vidya's use of *'the cell's way'* is a reference to emergent cellular behaviour from a class discussion. This had become a highly debated topic of discussion in the class, when Vidya explained to the rest, how these *random interactions* would result in emergent sensory behaviour of a cell.

Constructionist design

In the GenEvo course, the students learned emergent ideas by manipulating behaviours of computational agents and investigating system-level effects of those manipulations manifested in the microworld. Since every student used the same microworld, they developed a shared language to talk about those computational objects. These agent-level representations were 'object-to-think-with', which allowed students to collectively reason about emergent properties (Papert, 1980). This is how Sajid, Vidya's partner, investigated computational representations of proteins as objects-to-think-with to reason about a cellular behaviour.

"I was observing (potato-shaped things). So first I observed that it was just random movement. Then I saw that it was going on a straight line (on DNA), so I saw that it was rolling along the DNA. And then suddenly, when it went off pink triangles and rectangles were produced. I did this experiment 2 or 3 times and then I figured out that the RNAP produced LacZ and LacY…." (Sajid's interview, May 2018)

Sajid made an observation about a pattern that was related to the production of proteins, which were

[1] All the names used in this paper are pseudonyms.

represented as *pink triangles and rectangle*s pertaining to the movement of RNA polymerase (represented as a *potato-shaped thing*). He hypothesised that the movement of RNA polymerase on DNA is related to protein production. He verified it by repeating the experiment a few times under the same conditions. His carefully verified hypothesis become a piece in the puzzle that Vidya used to understand and explain the molecular mechanisms of genetic regulation.

In the GenEvo course, the agent-based restructurations of biological systems enabled students to develop a deep understanding of emergent ideas about genetic regulation and evolution. Traditionally they would have been told about these ideas authoritatively by their teachers using static models or animated videos to remember and then asked to explain those in the exams. Whereas in this course, students developed deep understanding of these ideas through ESM-mediated scientific inquiry. They collaboratively constructed knowledge about those ideas by asking questions, planning and carrying out investigations, analysing and interpreting evidence, and communicating their findings with others.

CONCLUSIONS AND IMPLICATIONS

ESMs and ESM-based curricula are design frameworks for learning environments to engage students in authentic scientific inquiry practices and learning about complex emergent systems phenomena. ESMs mediate students' expansive learning by providing them computational objects-to-collectively-think-with, in the context of a microworld. In the GenEvo course, students performed scientific investigations using these microworlds, shared their findings, argued about those, and developed a deep understanding about disciplinary ideas by engaging meaningfully in authentic scientific inquiry practices. Our analysis of ESM-mediated expansive learning revealed, how agent-based representations and constructionist design principles made ESM-based curricula effective for collaborative knowledge construction in a classroom setting.

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SURVEY OF STUDENT UNDERSTANDING OF ELECTRIC FORCE AND FIELD

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The basic purpose of this study is to find whether students can identify and overcome their deficiencies in a narrow range of concepts through self-reflection, self-study and self-sought discussion, induced by a large number of practice question focused on the concepts. For this purpose, a narrow range of concepts pertaining to electric force and field were tested. The pre-test consisted of the ten conceptual multiple-choice questions pertaining to electric force and field in the well-known Conceptual Survey of Electricity and Magnetism (CSEM). After pre-test was administered, a large number of similar questions were sent to the students by e-mail and they were advised to ensure that they can answer such questions before a post-test to be administered within a few weeks. This survey covers more than 1000 Physics students at different levels of physics learning at different institutions.

INTRODUCTION

Physics is a concept-based subject. A central goal of Physics Education is to develop a proper conceptual understanding of students on different topics. Physics Education Research (PER) as a field of study emerged to provide reproducible and quantifiable conclusions related to conceptual understanding. It has created a large body of reliable knowledge to help improvement in physics instruction and techniques. Physics Education Researchers have developed several standardized concept-tests in different topics in Physics that have to satisfy stringent requirements of reliability and validity (Adams & Wieman, 2011; Engelhardt, 2009). These tests are administered before instruction and after instruction. The learning gains on such concept tests help compare the effectiveness of different instruction strategies. The standard definition of learning gain in PER is the ratio of 'increase in percentage score' and '(100 – percentage pre-score)' the latter being the maximum possible increase in the percentage score. PER studies have consistently demonstrated that interactive engagement techniques lead to significant gains in conceptual learning as compared to traditional lecture-based instruction (Hake, 1998) leading to the introduction of reformed Physics programs at several places (Crouch & Mazur, 2001). The Force Concept Inventory (FCI) (Hestenes, Wells & Swackhamer, 1992), Force and Motion Conceptual Evaluation (FMCE) (Thornton & Sokoloff, 1998), Brief Electricity and Magnetism Assessment (BEMA) (Chabay & Sherwood, 1997) and Conceptual Survey of Electricity and Magnetism (CSEM) (Maloney, O'Kuma, Hieggelke, & Van Heuvelen, 2001) are amongst the concept tests which have been widely used for investigating students' understanding. In most studies, the pre-tests are administered in the initial weeks of a semester course and post-tests towards the end of the semester. Concept tests such as BEMA and CSEM cover many sub-topics and concepts in Electricity and Magnetism. Such coarse-grained tools can help compare broadly the efficacy of different instruction strategies, but are not useful for identifying conceptual deficiencies in an individual student and for taking remedial action. For this purpose, it is necessary to administer fine-grained concept tests and reduce the time lag between pre- and post-tests. Here, the pre-test and the post-test mean tests administered before and after a remedial intervention. Accordingly, the ten questions in CSEM pertaining to electric force and field were taken as constituting a fine-grained pre-test. This subset (CSEFF = Conceptual Survey of Electric Force and Field) consists of ten multiple-choice questions (or items). One of the reasons, for choosing CSEM was that the performance on individual questions in pre- and post-tests in the CSEM are available for comparison with our survey, even though the meaning of pre- and post-test in CSEFF is different. The broader purpose of our studies is to quantify the impact of different types of remedial actions for overcoming conceptual deficiencies. In today's world it is easy to get information, therefore an important, perhaps the most important, learning goal is to develop the ability to answer questions through self-study, through self-sought discussion with peers and instructors, and through self-reflection. This ability is expected to improve with the advancement of learning stages. Unlike FCI, CSEM is a broad survey instrument. There cannot be a single concept inventory for such a broad range of topics. However, CSEFF, a sub-set of CSEM, can serve as a single concept inventory for Electric Force and Field, comparable to FCI. In the present study, after administering the pre-test, a large number of similar questions were sent to the students by e-mail and they were advised to ensure that they can answer such questions before a post-test to be administered within a few weeks. The pre-test, post-test and the set of intervention practice questions can be obtained by email. In this way, an attempt is made to evaluate the unsupervised self-learning skills that students have developed for answering a class of similar questions pertaining to a very narrow range of concepts. In addition, the survey was also carried out over participants in a refresher course for college and university teachers from all over India, held at the Physics Department, a leading Indian University. All the participants had Ph.D. degrees and varying lengths of teaching experience. They are well set on the path of Physics learning and teaching as a profession. Compared to students, they can be expected to have better self-learning skills and therefore better ability to overcome any deficiencies on the pre-test.

The following research questions are addressed in this study:

- How do statistical test characteristics of CSEFF compare with recommended values?
- How do the option choices for different items vary with the ability of students?
- To what extent does the unsupervised intervention of self-directed study, induced by several similar problems, help improve conceptual understanding of narrowly focussed concepts?
- What conceptual difficulties are indicated by CSEFF and how do they compare with those reported for CSEM?
- To what extent does the conceptual understanding of electrostatic force and field improve with learning stages from B.Sc. I Year to M.Sc. Final.

METHODOLOGY

The CSEFF was administered as a pre-test to students at various stages of physics learning from a B.Sc. First Year to M.Sc. Final Year and to participants of the refresher course, without any pre-announcement. The reason for not giving any advance notice was to evaluate the internalization of concepts and not memorization for a test. After the completion of the pre-test, a set of 57 problems were sent to the students by email. Twenty of the self-study questions (two for each item on the pre-test) were minor variants of the ten items on the pre-test, therefore presumably had the same difficulty level. The remaining were a mix of simpler and more complicated versions of the items on the pre-test. The answers were not given, as the purpose was to evaluate problem-driven self-learning skills. Students were advised to ensure that they can answer such questions before a post-test to be administered any time between one to four weeks. A post-test consisting of questions very similar to the pre-test was administered, again without announcing the exact date of such test. Each item in the post-test was a minor variant of the corresponding item in the pre-test, allowing the computation of item-wise learning gains.

DATA ANALYSIS

Table 1 shows the percentage of students who chose different options for each item on CSEFF. Table 2 shows item-wise percentage correct response on pre-test and post-test. It also shows the learning gains for each item. Table 3 shows the item-wise correct response at different stages of learning. It also includes a column of the reported response in the pre-test given to introductory students in US universities.

Item		N	A (%)	B (%)	C (%)	D (%)	E (%)
1	Pre-test	1070	4	**67**	15	13	1
	Post-test	770	11	14	**69**	5	1
2	Pre-test	1063	9	**58**	13	19	1
	Post-test	768	18	14	**60**	8	0
3	Pre-test	1050	15	7	**58**	15	6
	Post-test	758	23	17	11	**42**	7
4	Pre-test	1062	14	23	18	15	**28**
	Post-test	767	10	17	**53**	8	11
5	Pre-test	1044	28	**21**	23	16	12
	Post-test	754	26	**33**	23	11	6
6	Pre-test	1049	8	**28**	21	26	17
	Post-test	762	12	25	24	**31**	8
7	Pre-test	1051	8	**28**	24	28	11
	Post-test	758	11	17	35	**21**	15
8	Pre-test	1047	11	33	**22**	13	21
	Post-test	750	22	**26**	26	19	8
9	Pre-test	1053	12	13	15	**47**	13
	Post-test	759	12	15	16	**46**	10
10	Pre-test	1061	22	23	**25**	15	15
	Post-test	763	22	26	**27**	14	11

Item	Topic	CSEFF Pre N ~ 1000	CSEFF Post N ~ 1000	Learning gain = (post – pre)/ (100 – pre)
1	Coulomb's law	67	69	0.061
2	Coulomb's law	58	60	0.048
3	Coulomb's law	58	42	-0.38
4	Coulomb's law + Principle of superposition	28	53	0.35
5	Coulomb's law	21	33	0.15
6	Coulomb's law + Principle of superposition	28	31	0.042
7	Coulomb's law + Principle of superposition	28	21	-0.097
8	Electric field + Newton's law	22	26	0.051
9	Electric lines of force	47	46	-0.019
10	Electric Lines of Force	25	27	0.027
	Average	**38**	**41**	**0.048**

Table 1: Percentage of student chosing different option, **Table 2:** Learning gain

		US Pre	B.Sc. I	B.Sc. II	B.Sc. III	M.Sc. Previous	M.Sc. Final	Refresher Course Teacher Participants
Item	Topic	N~1000	N = 434	N = 290	N = 134	N = 95	N = 55	N = 26
1	Coulomb's law	74	64	76	71	73	82	65
2	Coulomb's law	44	53	55	72	63	71	46
3	Coulomb's law	39	31	57	60	61	71	50
4	Coulomb's law + Principle of superposition	61	48	32	29	29	40	38
5	Coulomb's law	25	26	20	24	24	25	35
6	Coulomb's law + Principle of superposition	51	26	27	37	29	25	38
7	Coulomb's law + Principle of superposition	48	21	25	31	29	35	42
8	Electric field + Newton's law	24	21	18	22	22	35	23
9	Electric lines of force	60	37	44	49	62	58	69
10	Electric Lines of Force	17	23	24	24	21	24	31
	Average	44	**35**	**38**	**42**	**41**	**47**	**44**

Table 3: Item wise correct response at different stages of learning

Statistical characteristics

Some of the statistical characteristics (Ding, Chabay, Sherwood & Beichner, 2006), that are often used in PER for ensuring their reliability and validity are item difficulty index, item discrimination index, point-biserial index, KR-21 reliability index, Ferguson delta. It is necessary to evaluate these characteristics for the CSEFF as they depend also on the student population.

Difficulty index of an item: The difficulty index of an item in the test is defined by;

$$P = N_1/N \tag{1}$$

Here N is total number of students and N_1 is the number of students choosing the correct option, thereby scoring 1 for the item. The difficulty index for different items of CSEFF is shown in Fig 1(a). None of the items has difficulty index less than 0.2 or more than 0.7. The average difficulty index for the whole test is 0.38.

Discrimination index of an item: The discrimination index of an item gives information about the contribution of the item for discriminating between high scoring (> 75 percentile) and low scoring (< 25 percentile) students on the entire test. It is defined by

$$D = 4(N_{H-} - N_L)/N \tag{2}$$

where N_H and N_L are the number of correct responses to the item by the high scoring and low scoring groups respectively. According to classical test theory, items (e.g. 1, 2 and 3) with difficulty index around 0.5 are likely to have high discrimination index and items with difficulty index away from 0.5 (whether on the high side or the low side) are likely to have low discrimination index. Fig.1(b) shows the discrimination index for different items of CSEFF. The average value of the discrimination index is 0.48. An item is considered to have satisfactory discrimination if the discrimination index is greater than 0.4. Only items 8 and 10 failed this condition.

Point Biserial reliability Index: The point biserial index, a measure of the consistency of one item with the whole test, is defined by the correlation between the item score and the total score. It is given by

$$r_{pbs} - \frac{\overline{X}_1 + \overline{X}}{\sigma x}\sqrt{\frac{P}{1-P}} \qquad (3)$$

where $\overline{X}_1$ is the total score average for the students who answered the item correctly, $\bar{x}$ is the total score average for the whole test, σx is the standard deviation for the whole test and P is the difficulty index. Fig.1(c) shows the point biserial coefficient for each item of CSEFF. An item is considered good if its point biserial is > 0.25 and the recommended average value is ≥ 0.2. For CSEFF, all items had point biserial > 0.3 with an average of 0.4.

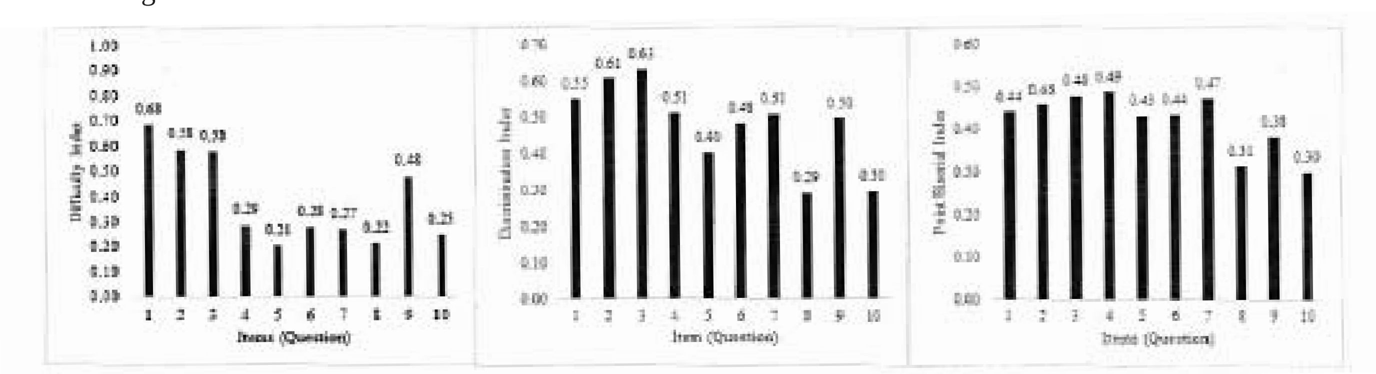

Figure 1: (a) Difficulty index, **Figure 1(b):** Discrimination index, & **Figure 1(c):** Point Biserial index

KR-21 test reliability index for the whole test: The Kuder Richardson reliability index measures the self-consistency of the whole test. KR-21 reliability index is the average correlation between all possible divisions into two parts, each having half the number of items. For a dichotomous multiple-choice test, it is given by

$$r_{test} = \frac{K}{K-1}\left(1 - \frac{\sum P(1-P)}{\sigma_X^2}\right) \qquad (4)$$

Here K is the total number of test items in the whole test, P is difficulty index and σx is the standard deviation of the total score. The recommended value for a good test is $r_{test} \geq 0.8$. For CSEFF the value of is 0.98.

Ferguson delta for the whole test: Ferguson Delta is a measure of the discriminatory power of the whole test. Let, be the number of students whose total score is i. Ferguson's delta is defined by;

$$\delta = \frac{K+1}{K}\left\{1-\sum_{i=0}^{R}\left(\frac{f_i}{N}\right)^2\right\} = \frac{N^2-\sum_{i=0}^{k} f_1^2}{N^2-\frac{N^2}{K+1}} \qquad (5)$$

For a good test, it is recommended that Ferguson delta should be > 0.9. The value of Ferguson's delta for CSEFF is 0.93.

Item response curves

Table I shows item-wise percentage responses to different options both for the pre-test and post-test. The correct option is shown in bold. This table gives the overall performance of all students without distinguishing between the varying abilities of students. The total score on the test may be taken as a measure of the ability of students. The response data is separated for students of varying ability as indicated by the total score. A table, like Table I, is prepared separately for each value of the total score. The data for all such tables is represented in the form of Item Response Curves (IRC) (Morris et al., 2006; Morris et al., 2012) as shown in Fig 2(a) for pre-tests and 2(b) for post-tests. As expected, with increasing ability the IRC's show an increasing trend for the correct option and a decreasing trend for the wrong options. For low scoring items like 5, 7, 8 and 10, the IRC's of the correct options start from 0 and rise steeply only at mid or high ability levels. For high scoring items like 1, 2 and 3, they start at relatively high values and rise slowly to flatten out as mid and high ability students have a high probability of answering them correctly.

Impact of interventional questions

The extent to which unsupervised intervention of self-directed study, induced by several similar problems, helped improve conceptual understanding of electrostatic force and field is shown in Table II. The average learning gain is a modest 0.048. Most of the items showed very little change. Item 4 was the only item that showed substantial learning gain. There was a substantial decrease in the correct option for item 3 and an increase in the wrong option (a). In the post-test, the distance was decreased, instead of increasing. It seems that several students still have problems in dividing by a fraction, causing a substantial increase in option (a). In figure 2(c) we show for each item, the correct option IRC's for pre- and post-tests juxtaposed together. Item 7 in figure 2(c) reveals a surprising and inexplicable feature: low ability students show improvement in the post-test, whereas high ability students show a decline.

Identification of misconception

As in CSEM, item1 was the easiest item in CSEFF for students of different abilities and at different learning stages in pre-tests as well as post-tests. Analysis of distractor responses to this item throw some surprising insight about possible misconceptions. About 15% answered that the force on a charge remains unchanged if the magnitude of the other charge is increased by a factor of 4. About an equal number answered that the force will decrease by a factor of 4. These answers are far more frequent than the other wrong options for no apparent reason. This trend is seen for items 1 and 2 in the pre-tests as well as the post-tests. This suggests that the wrong options are the consequence of misconceptions rather than random choices.

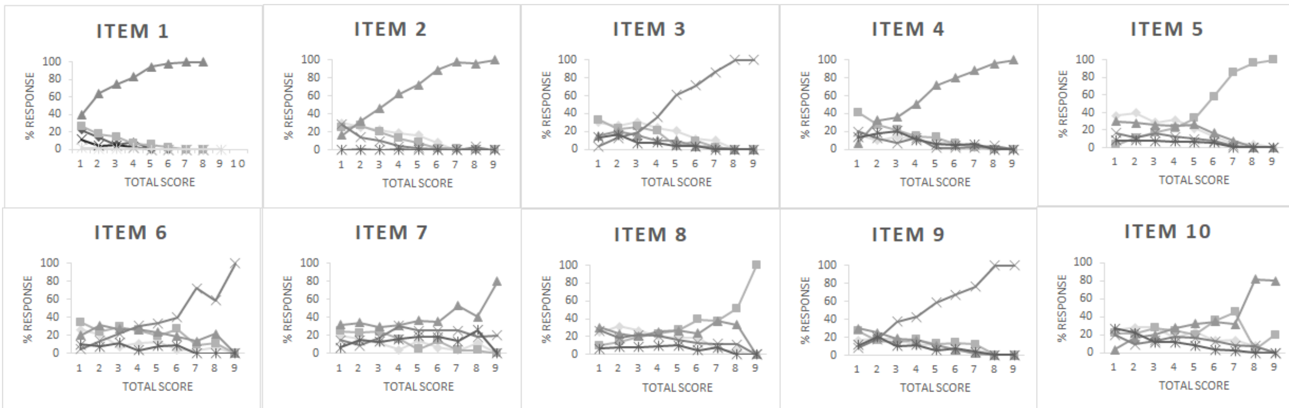

Figure 2(b) Post-test IRC's [✧ is option (a), □is option (b), Δ is option (c),x is option (d) and * is option (e)]

Figure 2(c) [◇for pre-test and □ for post-test]

In CSEM, the number of correct responses to item 2 were about 33% less than to item 1, although from an expert perspective, the two items are almost identical. Commenting on this result, it was remarked in (Maloney, *et al.*, 2001) that many students do not apply Newton's Third Law or symmetry of Coulomb's Law, that students seemed to believe that larger objects (in this case larger charges) exert larger forces than smaller objects. In CSEFF, the number of correct responses to item 2 were only about 14% less than to item 1. Responses to items 1, 2 and 5 do not support the view that students believe that greater charges exert greater forces. The distribution of wrong responses in CSEM is very different from those for CSEFF. Item 3 tests the understanding of distance dependence of electrostatic force between two charges. The problem with this item is that it is not independent of item 2. Those who get answer to item 2 wrong due to some misconception, cannot answer item 3 correctly. In CSEM, the number of persons who answered item 3 correctly was slightly less than those who answered item 2 correctly, suggesting that some students have problems with the inverse square dependence of the Coulomb's Law. In the CSEFF pre-test, however, both items 2 and 3 were answered correctly by the same percentage of students, suggesting that they do not have problems with the inverse square dependence.

In CSEFF, item 4 was answered correctly by only 28% students in the pre-test and 53% students in the post-test. This was the only item with substantial learning gain. From an expert perspective, items 6 and 7 are the most difficult in CSEFF, as they involve relatively lengthy problem description, intermediate stage inference and reasoning skills. These items were correctly answered by 28% students only, substantially less than CSEM students.

Items 8 and 10 were the most difficult in our survey, with difficulty index less than 0.25. Table III shows that in the reported CSEM studies also, pre-test scores on items 8 and 10 had difficulty index less than 0.25. As in CSEM, the number of students in CSEFF who answered item 8 correctly was much less than those who answered item 9 correctly, suggesting that many students still thought that application of constant force on a body would give rise to constant velocity.

CONCLUSION

CSEFF is a reasonable fine-grained instrument for assessment of conceptual understanding of electric force and field, which satisfies the statistical parameters recommended for concept tests. Item Response curves (Figure 2) provide graphs of how student performance on different options vary with ability. These graphs are easy to interpret and provide useful insight. The average learning gain due to self-learning questions was a modest 0.048. Only item 4 showed substantial learning gain. This could be because the correct option in the pre-test was 'none of these' which students tend to avoid. As argued in subsection III, substantial negative learning gain for item 3 could be due to students having problem in dividing by a fraction. Inexplicably, the performance of low ability students on item 7 improved in the post-test, whereas that of high ability students deteriorated. A serious limitation of our study is that it relies wholly on intrinsic motivation for students to try and do well in the post-test. In future studies we plan to introduce some extrinsic motivations so that students work on the intervention problems more seriously towards better performance on the post-test. It seems that a large number of students have problems with the principle of superposition and/or vector addition. A finer grained survey will be conducted for understanding the detailed nature of the misconceptions related to the principle of superposition as a follow-up of the present survey. Compared to CSEM, performance of CSEFF students was substantially poorer on problems involving lengthy description, intermediate stage inference and reasoning skill. Overall performance of students in CSEFF was found to increase slightly with advancement of learning stages from BSc I year to M. Sc. Final. The table shows a significant improvement only at the M.Sc. Final stage. This shows that students do not improve their understanding of electrostatic force and field with advancement of learning stages. Improvement at the final year stage could be because students start preparing for entrance tests for research programs, which test understanding of basic physics concepts better than the more memory-based tests in their regular courses. However, the performance of teacher participants in the Refresher Course was very disappointing and should be a cause of concern for Physics Education in India. Inferences drawn from CSEFF are suggestive and require carefully planned studies for confirmation.

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UNDERGRADUATE STUDENTS' MENTAL MODELS OF ELECTROSTATIC POTENTIAL

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Electromagnetism (EM) is considered as one of the essential components of core physics course where 'Electrostatics' lies at its foundation. 'Electrostatic Potential' is one of the most crucial concepts introduced in electrostatics connecting most fundamental physical quantities namely, electrostatic field and potential energy. Therefore, clarity in understanding of electrostatic potential is crucial for interaction of charges (or charge distributions) with an electric field. Since it is presented at undergraduate level in a highly mathematical and abstract framework, there remains scope for development of students' mental model which are divergent from the well-negotiated scientific concepts. Therefore, in this study, we have made an attempt to explore students' mental models for the concept of 'Electrostatic Potential by using problem solving tasks and interviews. We have found significant alternative conceptions which pose a challenge for meaningful learning.

INTRODUCTION

Electromagnetism (EM) is amongst the core subjects in undergraduate physics curriculum and plays a pivotal role in the development of many applied as well as interdisciplinary areas in physics. At the undergraduate (UG) level, EM is introduced conceptually with electrostatics in a highly abstract and mathematical framework (Griffiths, 2013). Electrostatics is substantially less intuitive than classical mechanics (which is introduced first at the UG level) and therefore, in addition to the common sources of misconceptions borrowed from mechanics, there is a variety of sources which are related to the abstract new concepts of electrostatics (as well as magnetostatics). In fact, conceptual development of electrostatics through experiments at an undergraduate level is a rare occurrence (Dvořák, 2012). There are a very few 'classroom environment' experiments in electrostatics through which, quantifiable information could be derived (Dvořák, 2012; Liengme, 2014). Hence, the basis of certain assumptions as well as 'laws' in electrostatics could be interpreted by students in varied manner when the concepts are introduced to them. In addition, the complex nature of mathematically defined quantities (including vectors, complex numbers, derivatives etc.) in electrostatics results in unforeseen cross-linkages in conceptual framework and consequently, students may have varied mental models at the undergraduate level. Within the constructivist framework those mental models which are divergent from well negotiated scientific concepts of the given time can be referred to as alternative conceptions (AC). Such AC in the area of electrostatic force/field and current electricity have been investigated by a few groups across the globe, essentially from an application perspective (Bull, Jackson & Lancaster 2012; Aubrecht & Raduta, 2005; Baybars, 2019; Samsudin et al., 2019). In one of the recent studies, Lindsay

(2014) presented an exploratory investigation on UG students' conceptions about electrostatic and gravitational potential energy which is crucial for making sense of energy (potential) in chemistry as well as biology.
In electrostatics, potential energy in charged systems is essentially derived from basic understanding of electrostatic potential and field. In fact, electrostatic potential (scalar) is one of the most-used physical quantities in electrostatics as it connects all the three spatial components of electric field vector on one hand and electrostatic potential energy on the other. Due to the fact that the formal definition of electrostatic potential (V) entails unavoidable mathematical and abstract formalism, the physical picture of the concept of potential amongst UG students may be varied and therefore, the possibility of development of divergent mental models is high. Thus in the present work, we have investigated the mental models of the concept of electrostatic potential of a group of UG students majoring in physics.

RESEARCH QUESTIONS

- Does students face difficulty in understanding the concept of 'potential' in electrostatics? If yes, what could they possibly be.
- Do they consider that the presence of an electrostatic field results in existence of potential?
- Is it likely that they borrow idea from other concepts (such as potential energy, electric field) to associate a meaning to electrostatic potential?
- Is their mathematical understanding of 'potential' coherent with physical concept of potential?

METHODOLOGY

This research focuses on patterns of errors learners commit while solving the problems based on relationship between electrostatic field and electrostatic potential in the case of uniform electric field. The aim is further to explore if these errors are simple mistakes or do they have roots in students' conceptions of the scientific concept. Thus this study is situated in the qualitative paradigm where objective is to unravel the students' mental models of the concept as they solve problems. To this end we have selected three relevant questions from a standardized tool BEMA (Ding,Chabay,Sherwood & Beichner, 2006) . These questions were administered to the participants as a Quiz before the concept of 'electrostatic potential' was taught in the class. The questions were objective type with choices (a to g). For our purpose we had added another choice 'h' (any other). Students were required to choose the correct option in their view and also provide an explanation for their choice. Also after the Quiz each student was interviewed in detail about their responses and explanations. After the topic was done in the class another Quiz was administered with two multiple choice objective type questions. These questions were constructed by us and have 5 options (a-e) in which option 'any other' is included (Appendix). Again students were required to provide a correct choice followed by written justification for their choice and subsequently interviews regarding their explanations and choices were conducted.

The analysis has been done within the paradigm of constructivism with the basic assumption that each student constructs his/her own knowledge. The written responses and interview data was analysed together and some significant errors which were repeated by learners and had roots in students' conceptual understanding have been referred to as students' alternative conceptions and presented in the next section .

Participants for this research were a class of 18, 1st-year UG students of physics, studying at National Institute of Science Education and Research (NISER) situated in Odisha , India. The tests were conducted during the course on Electricity and Magnetism (EM). This is the first course of EM for students at undergraduate level, thus their prior conceptions about Electrostatics are those which they carried from their school level. Also, they have credited a course on classical mechanics prior to this course on EM.

RESULTS

The selected questions from BEMA are referred to here as Q1, Q2 and Q3. They are based on a situation where a uniform electric field is given in a plane and 4 points are considered. Students are required to find the potential difference between two points situated along the electric field in Q1, two points situated perpendicular to electric field in Q2 and two points which are diagonal to electric field in Q3. Options 'a', 'b','c' and 'd' of the MCQ indicate the potential difference between two given points as product of electric field and shortest distance between the given points with negative and positive signs . Choices 'e' and 'f' indicate the potential difference to be path dependent showing it to be the product of electric field and actual distance travelled to reach final point from initial point . Choice 'g' indicates the potential difference to be zero and another choice 'h' added by us indicates 'none of the above'. Other two questions constructed by the researchers are referred to as Q4 and Q5 and are given in Appendix. Students' choices are presented in table 1 given below. Students are referred to as S1, S2, S3…..S18 in the text.

Choices ---------- Question	a	b	c	d	e	f	g	h	Not Answered
Q1	S6,S14	S1,S2,S3,S4, S7,S8,S9,S10, S11,S12,S13,S15S16,S17,S18							S5
Q2							S1,S2,S3,S4, S6,S7, S8,S9,S10,S11, S12,S13,S14,S15, S16,S17,S18		S5
Q3	S6,S14	S1,S3,S7,S8,S9,S10,S11,S12, S13S15,S16,S17,S18				S2,S4			S5
Q4	S1,S2, S3, S5, S6, S7, S8, S9, S10, S11, S12, S13, S15, S16, S17, S18					-	-	-	S4,S14
Q5	S1, S3, S5, S6, S7, S11, S15, S17, S18			S8,S9, S10,S12, S13,S16		-	-	-	S2,S4,S14

Table 1: Students' Responses

We have observed the following alternative conceptions in the study.

E1: Potential is a vector

The concept of potential was specifically devised in electrostatics for the purpose of simplifying the complex vector calculations. It is negative gradient of electric field and thus a scalar quantity. While teaching, it is generally the third significant concept presented in the class after force and field. An important point to note is that force as well as field is a vector quantity. It was observed that many learners carried a strong alternative conception that potential was a vector. One of the reasons could be extrapolation of the properties of force and field which were presented prior in sequence to potential. This alternative conception was shown in many ways by learners specifically in Q1, Q2 and Q3. S2 directly expressed his belief in the interview that potential is a vector quantity. Further he could state the mathematical formula for potential to be a dot product between $\vec{E} \text{ and } d\vec{l}$, but he did not seem to understand the meaning of dot product as well (which is a multiplication between two vectors resulting in a scalar). On the other hand S17 depicted potential with a vector sign ($\overrightarrow{V}$) while solving the task in written form. He also depicted the relation between potential at two points in Q1 as $|V_1| > |V_2|$. Now, since the potential is a scalar quantity, the use of modulus does not hold any significant meaning here. While answering Q2, S17 mentioned "*potential is perpendicular to electric field*" i.e. he expressed potential in terms of a particular direction. It indicates that the learner extrapolated his conceptions of vectors to potential as well.

E2: Potential has an absolute value

Potential is defined with respect to a *conveniently* chosen reference, therefore we always measure potential difference instead of 'absolute potential'. While answering Q1, S17 wrote "*let* V1 = -Ew; V2 = -E +) = 0; V_2 -V_1 = –Ew; $|V_1| > |V_2|$ *which implies* $V_2 > V_1 = -ve$". Here, he equated potential at point 1 to '–Ew' which was incorrect since '–Ew' is the potential difference between point 1 and 2 rather than an absolute value at point 2. Also, it showed that he did not view potential to be a line integral of electric field over a path from one point to another. Instead, he understood potential to be having absolute values at various points in space which showed a clear alternative conception in his metal model.

Another manifestation of considering potential to have an absolute value was evident when S2 while answering Q4 marked the correct option but explained the reason in the following manner:

$$"V = -\int_a^b \vec{E}.d\vec{l} = -\int_a^b Ex.d\vec{l}\,, x, y = 0; \cos 90^\circ = 0;$$

At B and D V=0"; Since, points B and D were located on an equipotential surface thus, the potential difference between them was zero and not the value of potential itself.

E3: Only magnitude of field is important to calculate potential

Electric field is a vector quantity which comprises of both – magnitude and direction. While calculating potential difference between two points, dot product of field with distance between those two points is considered. It is important to note that the dot product involves only vectors and results in a scalar. Also, direction of both the vectors involved plays a crucial role while calculating dot product. Some learners were observed to believe that since potential is a scalar therefore to calculate potential only magnitude of field is important and the direction could be ignored which is an alternative conception. As a manifestation of this erroneous conception, S11 expressed in the first interview, that potential difference between any two points should be zero when magnitude of electric field is the same. She further added that these two points could be inferred to be on an equipotential plane, which is an incorrect inference.

E4: Negative sign in potential

Potential at a point P is defined as the negative integral of electric field with respect to distance i.e. . This negative sign depicts that the 'work', in bringing a test charge from infinity to point P, is done against the existing field due to some charges already present in the system. Thus, there is a physical reason for the negative sign being present in the equation. It was observed that students frequently missed this negative sign while calculating potential. Some learners were also observed to use it at their convenience, i.e. they used it in some questions and did not use it in other questions. Within the same task, S1 used it in one step and missed it in the other. Another student was observed to use a positive sign throughout the solution but brought a negative sign in the last step without stating any logic for inserting it. Due to the inconsistent use of the negative sign, at times learners were also observed to reach incorrect answers. For instance S6 got both his answers of Q1 and Q3 incorrect as he did not find any importance of negative sign in calculating potential. S2 although marked correct option as an answer to Q1, however while explaining in the interview he changed his answer to option 'a' explicitly mentioning that "*negative sign is only for indicating work done and not significant in calculating potential*". It shows that these learners lacked understanding of physical meaning of the concept as well as self-consistent mathematical framework to arrive at physically acceptable results.

E5: Limits of integration

Within a discipline, conventions are defined to make communication easier and less ambiguous. It helps everyone understand the same meaning of the given relation. In the case of integration, limits '*a*' and '*b*' are shown as $\int_a^b f(x)\,dx$ where '*a*' is the lower limit and '*b*' is the upper limit. Physically it means '*a*' is the initial point and '*b*' is the final point. While solving the integral the final relation is calculated as:

$$\int_a^b f(x)\,dx = [g(x)]_a^b = g(b) - g(a)$$

Learners were observed to show many errors regarding limits. Some learners (S1,S2,S4,S6) did not pay heed to the order of the limits (i.e. lower and upper) and calculated

$$\int_a^b f(x)\,dx = [g(x)]_a^b = g(a) - g(b)$$

Learners were observed to show many errors regarding limits. Some learners (S1,S2,S4,S6) did not pay heed to the order of the limits (i.e. lower and upper) and calculated

This interchange of limits changes the result by a negative sign which learners do not mention, resulting in incorrect answers, for instance Q1 and Q3 of S14. For some learners like S6 the order of limits did not matter while explaining the concept physically, he explicitly mentioned it in the interview. They interchangeably used the limits which showed that in their mental model the significance of order of limits as well as physical implications of a 'negative' sign in mathematical result was not important. Many of them felt that changing the sign would not make any difference because magnitude still remains the same. Whereas in the context of potential a positive or a negative sign represents whether work is done by the system or on the system which depict two independent and different cases. Another error noticed frequently was not mentioning the limits at all. Potential is a quantity which has a meaning only with respect to a reference point or in other words when a charge is moved over a distance (represented by dl) in the presence of electric field, only under that condition potential is defined. Hence understanding and mentioning the limits are very important while using potential.

E6: Potential is path dependent- Potential is derived from electric field using one of the most important properties of electric field i.e. conservative nature of field. It means curl of the electric field is zero i.e. it is irrotational. In other words, since curl of field is zero it can be expressed as a gradient of a scalar quantity which is defined as potential (V) in electrostatics. It also means that line integral of electric field is path independent or depends only on the end points. Therefore, in the relation

$$V(b) - V(a) = -\int_a^b \vec{E} \cdot \vec{dl}$$

dl can be chosen to be any arbitrary path from *a* to *b*. That is, for each different path chosen *V(b) - V(a)* will remain the same, because it only depends upon the end points and not on the path. Some students tend to overlook this basic property while solving tasks. S4 marked correct option for Q1 and Q2 , however for Q3 he marked option 'f' which was incorrect. In the explanation to his choice, he substituted the value of dl to be $\sqrt{h^2 + w^2}$, which was the length of shortest 'distance' between point 1 and point 4. He perhaps could not appreciate the path independent nature of potential difference, due to which he could not combine the inferences from his answers in item no. Q1 and Q2. S2 on the other hand had chosen option 'f' for Q3 however in the interview he changed his option to 'a' (as he did for Q1).

E7: Field same means potential same- It was a common observation that students interchangeably used the names of the concepts e.g. field for potential or force for field. One of the manifestations of this error is seen when they extrapolate the properties of one concept into another concept. In response to Q2, the reason cited by S6 for his answer was *"since E is same for both points and that is why V should also be same"* or in other words 'if electric field at any two points is same then potential difference between those two points is zero' is an alternative conception. There could be conditions contradictory to this, such as given in Q1, where E is same for points 1 and 2 but still potential was different. In another instance, a student assumed that the 'electric field is constant' on equipotential surfaces, i.e. when potential is same field should be same indicating the alternative conception held by him.

E8: Gradient: Mathematical definition and physical understanding- 'Gradient' (of a scalar) is a mathematical operation which is used for determining the direction and magnitude of maximum change of a scalar. In order to mathematically estimate the 'gradient', the functional form of scalar function (whose gradient needs to be evaluated) should be necessarily known. However, if the scalar function is a constant over a surface, then it is expected that the 'maximum change' in that function will be along the direction perpendicular to the surface. In other words, the direction of the gradient of the scalar function will be along the direction perpendicular to the surface. Using this result, it is straightforward to show that the gradient of electrostatic potential will always be in a direction which is perpendicular to the equipotential surface. Many of the learners as shown in table 1 above could not ascertain this point and hence, they chose option d:'lack of information' in Q5. For instance, S10 mentioned *"there cannot be any electric field along the Y and Z direction anyway due to symmetry. To know the electric field, one needs to know V as a function of r, knowing it on a single plane is not sufficient"*. Although it is correct that one needs to electric electric field at two planes but the direction of electric field (negative of the gradient of potential) could be ascertained from the location of one equipotential surface as well. He missed this point which shows that he knows the mathematical aspects of a gradient of a scalar quantity but cannot connect it to a physical situation always.

DISCUSSION AND CONCLUSION

In the section above, following alternative conceptions have been observed: a) Potential is a vector b) Potential has an absolute value b) Only magnitude of field is important to calculate potential d) Negative sign in potential e) Limits f) Potential is path dependent g) Identical field amplitude implies identical potential (alternately, uniform electric in a region implies constant potential). Such an observations is made on the basis of repeated patterns which students exhibited in multiple situations during the interaction.

It is evident from the results that students' correct answer may not always project the real conceptual understanding as most students marked correct options for the given tasks. Their written explanations and oral interview gave us an insight into how they thought about the concept and how they linked one concept to another. It was observed a few times that the students wrote correct formulae however while using them to solve a problem, they got confused. The response of S6 in **E5** is a case in hand where the limits written by him (in written response) does not carry significant meaning. At times they could not substitute the variables in the formulae with the correct values given in the problem. A similar case is represented by S1 in **E4**. Incidents such as neglecting negative sign while calculating potential (S1 in **E4**), using incorrect order of limits or ignoring them altogether, not being able to utilise the concept of gradient to find direction of electric field (S10 in **E8**) shows a clear missing link between the mathematical representation and physical representation of the concept in their mental models. Further, aspects like interchangeably using the terms'field' and 'potential' at times (S6 in **E7**) not only shows naive error, it also reveals that the concepts are not delineated in students' mental models which, at times, result in one-to-one mapping of one concept to another. This issue may give rise to alternative conceptions such as considering potential as a vector (S2 and S17 in **E1**) and considering potential to be same at two points if electric field is uniform (S3 and S4 in **E6**). It, therefore, indicates a decent room for improvement in our teaching-learning classroom techniques in this topic which is accepted to be quite abstract. Possibly, after introducing the concept of 'potential' in formal manner, the students could be subjected to solve a variety of mathematical problems which require visualisation of concepts. For example, a question on estimation of 'field' and 'potential' for a symmetric charge distribution may be followed by tracing/drawing the equipotential surface. A well-designed mixed bag of questions related to one or related concepts may bring out inconsistencies in conceptual framework and subsequently rectify it as well. At times, a teacher needs to approach a problem in an unconventional (non-trivial) direction. Such reverse approach tends to create disequilibrium in case misconception/alternate conception exists. For example, estimation of a possible charge distribution from a pictorial representation of an equipotential surface could bring out inconsistencies in understanding of the relation between equipotential surface and electric field. However, this necessarily needs to be complemented with honest acknowledgement and analysis of the error. Eventually, such alternative conceptions must find an appropriate space in classroom discussions. Such an approach could help learners reflect on their concepts and find the points of divergence between what they understood and the widely accepted (well-negotiated) scientific concepts of the given time, further encouraging them to construct viable concepts.

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LEARNING BASIC ASTRONOMY THROUGH AN EMBODIED AND INTERACTIVE APPROACH

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Students and adults struggle to understand the explanations of simple astronomical phenomena. Research has shown that much of the difficulty lies with students' difficulty to use visuospatial reasoning. Drawing on research on embodied cognition, multimodality and multimedia learning, a short pedagogic sequence called 'Basic Astronomy module' was designed around multiple external representations such as concrete models, gestures, role plays, animations, interactive digital games and diagrams. In the present study, we closely monitored the implementation of the module by seven teachers in government schools in Jaipur district of Rajasthan, India to study the teaching-learning process through the module and its effectiveness. In this paper, we will document the learning outcomes of the module in terms of conceptual understanding, attitudes and beliefs. Results show that students' understanding of basic astronomy concepts improved significantly after completion of the module; additionally, students' beliefs and attitudes towards science and specifically towards astronomy changed.

INTRODUCTION

Foundations of astronomy such as the model of the solar system and explanations of commonplace phenomena such as the occurrence of day and night, seasons, phases of the moon, solar and lunar eclipses are part of high school curricula in most Indian states. Earlier research in science education documents that alternate conceptions about the earth and astronomical phenomena are common among students (Vosniadou & Brewer, 1992, 1994; Padalkar & Ramadas, 2008). These alternative conceptions are often retained after instruction, or sometimes new alternative conceptions are developed (Bailey, Prather, & Slater, 2004; Lelliott & Rollnick, 2009). Thus many adults, including teachers, have alternative conceptions in the area of astronomy (Raza, 2002; Abell, 2007).

Models in astronomy, such as that of the solar system, include spatial information such as size, shape, distances, relative positions and trajectories of celestial bodies. Understanding models and explanations of commonplace phenomena such as the occurrence of day-night, seasons, phases of the moon and eclipses requires visuospatial thinking. For example, day and night are caused due to the rotation of the earth whereas the seasons are caused due to the revolution of the earth with its axis tilted. However, many students think that day and night occur due to the revolution of the earth (Vosniadou & Brewer, 1994) and seasons occur due to the change in the distance between the sun and the earth due to the earth's elliptical orbit (Lelliott & Rollnick, 2010). Thus, difficulty in visuospatial thinking is one of the main reasons for difficulty in understanding basic astronomy and emergence of alternative conceptions (Kikas, 2006; Subramaniam & Padalkar, 2009; Padalkar & Ramadas, 2010; Plummer, Kocarelli, & Slagle, 2013).

Our understanding of space is developed through the combination of visual, haptic, kinesthetic and vestibular perception. Hence, the corresponding external representations such as visual images (diagrams, photos, and animations), handling of concrete models, gestures and bodily actions should be used to teach content which requires spatial thinking. Diagrams play a crucial role in learning science and are commonly used as a pedagogic tool in textbooks and classrooms (Ainsworth, Prain & Tyler, 2011). However, diagrams are two dimensional, static and abstract (i.e. not realistic) and hence pose a difficulty to learners (Mishra, 1999). Drawing from the research on embodied cognition and multimodality, Padalkar and Ramadas (2008, 2010) proposed a pedagogic sequence of concrete models, gestures & actions (referred here as role-play) and diagrams to teach basic astronomy. Similar attempts to use the role-plays and gestures to teach astronomy are documented in Crowder (1996) and Venkateswaran & Gupta (2009). However, we adopted the sequence proposed by Padalkar and Ramadas since it weaved different spatial representations. Also, in previous research, this pedagogy was found to be effective in addressing alternative conceptions and developing a rich and accurate understanding of astronomy. Students who underwent this pedagogy also developed good representational competence (Padalkar, 2011).

The digital medium is another powerful medium which could be included in such pedagogy. Animations can overcome the limitations of diagrams to convey motion and to some extent three-dimensionality. The advantage of diagrams and gestures is that the learner can generate them. On the other hand, it is difficult to generate concrete models and animations for a learner. However, both afford a certain amount of interactivity. In addition, the digital medium can provide instant automated feedback and if the feedback is detailed and appropriate students can use it to learn. Keeping the general theme in mind, we selected some part of the pedagogic sequence proposed by Padalkar and Ramadas (2008, 2011) and added digital activities to the module. The activities suggested by Padalkar and Ramadas (2008, 2011) were appropriated in such a way that they complement the digital activities and the module was more suitable for large-scale implementation. The purpose of this paper is to describe an intervention that utilized a combination of technology and embodied pedagogic strategies to improve high school students' understanding of basic astronomy concepts. Additionally, we examined changes in students' attitudes and beliefs about astronomy. The intervention was implemented as part of a large-scale initiative targeted toward government schools in four states of India. This work is significant in that it strives not only to mitigate a problem common to high school students in general, but it seeks to do this in a population that is under-resourced and often under performing.

METHODOLOGICAL APPROACH/ MODULE DESIGN AND CONTENTS

The module was developed via iterative design and development phases. Several classroom and individual trials were done during the development phase of the module (Chopde & Padalkar, 2018). The first round of implementation took place in Grade 9 classrooms of government schools in Rajasthan (documented in

Shaikh, Chopde & Padalkar, 2018) based upon which we revised the module and finalized the support material for the teachers. Both the module and the support material for teachers are available in both English and Hindi. As shown in Figure 1, the module is divided into three units. Each unit contains four lessons that last approximately 40 minutes each. Thus there are twelve lessons, comprising eight hours in all. Three out of twelve lessons are digital lessons which are to be conducted in a computer lab. The remaining nine lessons contain hands-on activities and discussions which are to be conducted by the teacher in a regular classroom. All of the lessons can also be accessed via weblink. The module used free and open software and will soon be released as an Open Educational Resource (OER).

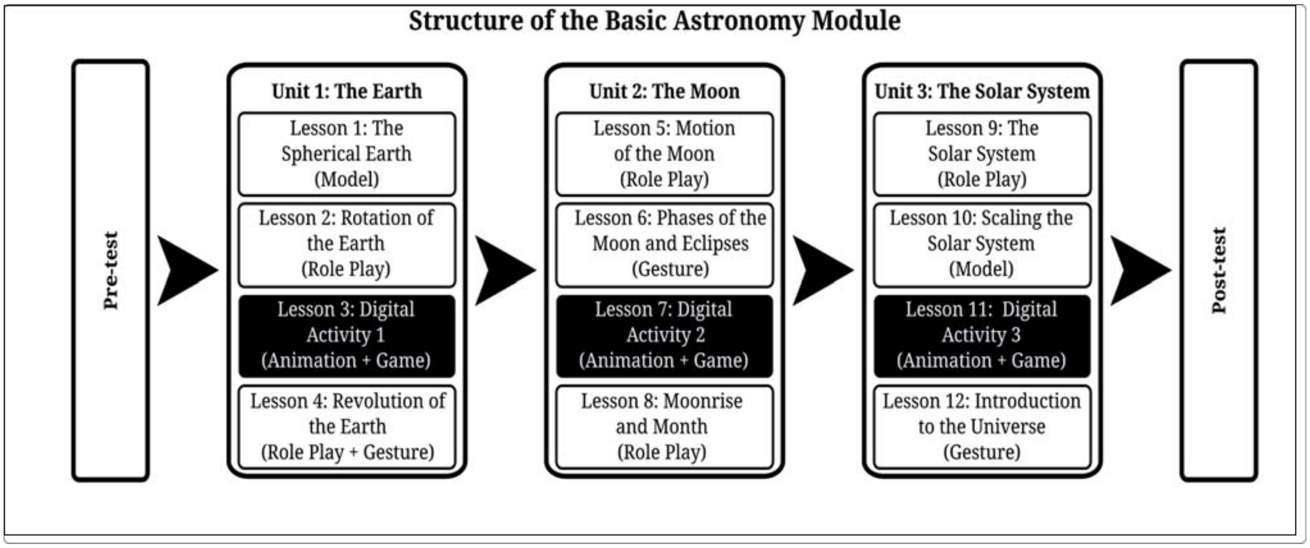


Figure 1: Structure of the 'Basic Astronomy' module

Classroom activities

As mentioned earlier, the classroom lessons consist of activities and related discussions. The number of activities focused on different kinds of spatial representations in each unit are shown in Table 1.

Unit No.	Concrete Models	Gestures	Role-plays	Diagrams (given + asked to draw)	Photos	Videos
1	3	2	5	17 + 7	0	0
2	1	1	5	11+6	8	0
3	1	1	1	3+1	23	2
Total	5	4	11	61+14	31	2

Table 1: No. of activities focused on different kinds of spatial representations

An example of use of a concrete model would be geosynchron (axis of the globe is parallel to the Earth's axis, pointing towards Pole Star). The lesson in which the geosynchron is used includes putting it in direct sunlight and observing the time of day at different locations. Examples of gestures used in the module include the right-hand thumb rule to determine the direction of the rotation and revolution of the earth and to trace the path of the sun at different latitudes and in different seasons. An example of role play is to mimic the motion of the moon to understand why we see phases of the moon. Note that different role plays were used to explain different phenomena. Most of the explanations are accompanied by diagrams, or students are required to draw a diagram after they complete the role-play activity. Photos of most of the celestial bodies which are discussed in the module are provided and two short videos on stars and galaxies are also included in the end. Teachers are expected to show the photos and videos in the classroom and to initiate appropriate discussions about them.

Digital activities

We used the multimedia principles of Mayer (2014) as guiding principles to design our digital content. All digital lessons are divided into two activities. In the first activity, students see animations. The animations include representations from different perspectives (to convey the three-dimensional nature of the systems) and mainly emphasize the motions of the celestial bodies. Some of the animations also morph into diagrams to help students see the correspondence between an animation and diagrams they regularly see in textbooks and classrooms. The second activity of the digital lesson includes a digital game called AstRoamer (divided into three parts, one part for each unit). The details of the digital activities are shown in Table 2.

Unit No.	Lesson No.	Activity 1: Animation	No. of Animations	Activity 2: Game	Astronomy Concept	No. of demos + No. of clues
1	3	Rotation of the earth	4	AstRoamer: What's the time	Rotation of the Earth and time of the day	1 + 7
2	7	The motion of the moon	3	AstRoamer: Moon Track	Phases of the moon	1 + 7
3	11	Solar System	4	AstRoamer: Planet Trek	characteristics of planets	0 + 10

Table 2: Details of the digital lessons

Apart from multimodality to facilitate the visuospatial thinking which is crucial in learning astronomy, three more guiding principles directed the design of the module: Collaborative Learning, Authentic learning and Learning from mistakes.

Collaborative Learning: Most activities in the module are to be done in pairs or groups. For example, in Roleplays students become different celestial bodies and mimic their motion. Given that the school labs have a limited number of computers (typically 10) and the number of students is at least 20, we expect that two students will use one computer when they are in the computer lab for the digital lessons. We have deliberately designed the first part of the digital game (AstRoamer: What Is the Time?) for two students to answer alternately so that students can discuss while solving the problems, and hope that it will set the trend for the rest of the activities.

Authentic Learning: India has a rich tradition of astronomy and has a variety of calendars (some are lunisolar some are lunar and some are solar). Since most of the festivals fall on a particular phase of the moon, students are well aware of the calendar used in their area. We tried to bring this aspect to the module by explaining terms used in the indigenous astronomy and designing the second part of the digital game (AstRoamer: Moon Track) around phases on different festivals. Incidentally, the terms used in indigenous astronomy and astrology are the same. We hoped that explaining them will demystify them and help students to think rationally about the astrological claims.

Learning from mistakes: In the digital game (AstRoamer), each trial has two chances. Case-specific feedback is designed which appears after the first wrong answer to help students find the correct answer. Teachers were also encouraged to ask open-ended questions to students and use their incorrect responses are resources to engage in the discussion rather than giving immediate feedback in terms of right or wrong.

STUDY PROCEDURE

For this study, we chose thirteen schools in Jaipur district with the following criteria of selection:
1. The number of students in the class was less than 40.
2. Computer lab had a minimum of 9 terminals working.
3. Schools were not too far from Jaipur to allow for classroom observations
4. Teachers were willing to participate: To ensure the authentic implementation of the module it was necessary that the teachers teach the module in their respective schools instead of allowing designers or experts to teach it.

The teachers from the selected treatment schools had access to the module on their school computers, and we also provided a hard copy of the support material two weeks before the study started. However, we anticipated that teachers would not be familiar with the module by the onset of the study and would also require on-site support. Prior to the study start date, we held a face to face workshop in which we took the teachers through half of the module in the same way the students would experience it. Out of 13 teachers who indicated interest in the study, only eight teachers attended this workshop, so we reduced our treatment sample to students in those eight schools.

Students completed a pre-test before the implementation of the module in their classes. The pre-test included 20 questions based on the content covered in the earlier grades or things that students would know from simple observations or social interactions (19 multiple choice questions, one question which required students to draw a diagram), 5 questions on attitudes towards science and astronomy and two questions related to beliefs regarding astronomy. In the next 6 working days, teachers were asked to teach the first six lessons of the module (approximately one each day). We held another workshop for teachers on the seventh working day to cover the remaining half of the module with them. We also shared pre-test results with the teachers and highlighted the major difficulties which their students faced. Seven out of the eight original teachers attended this workshop; thus we continued the study with those seven teachers and their respective schools, leaving data from seven participating schools for analysis. The study was concluded with the post-test and teacher interviews. The first 20 questions of the pre and post-test were equivalent; the post-test contained 5 extra questions on the content which was not taught in earlier grades but covered in the module. The study procedure is summarized in Table 3.

Teachers attended the first face-to-face workshop	
Student Pre-test	
* Teachers taught and students engaged in the Basic Astronomy module * Minimum two classes were observed by CLIx team member * Observed classes and teacher interviews were audio recorded	* A second face to face workshop for teachers was scheduled after half of the module was implemented (i.e. on the 7th working day). * The total number of working days between the pre and post-test (excluding the days of workshop) was 11 or 12 (typically included 12 lessons).
Student Post-test	

Table 3: Study Procedure

The study also included a control group but we have not included that part of the study considering the limited scope of this paper. The procedure and findings of the larger study are documented in more detail in TISS (2019).

SAMPLE

Grade 9 students of seven government schools from the Jaipur district of Rajasthan, India participated in the present study (school wise breakdown is displayed in Table 4). There were a total of 243 students, 106 boys and 137 girls, who participated in the study. The age of the students was between 13 to 15 years, and most of them came from low socio-economic areas. All participating schools were from rural areas of Rajasthan. The medium of instruction in all of the schools was Hindi. However, all students spoke a dialect of Hindi called Rajasthani when not in the classroom; inside the classroom most of the time they spoke in 'standard' Hindi.

School	Students		Total Number of Students	Teacher
School A	10 Boys	11 Girls	21	1 Female
School B	19 Boys	23 Girls	42	1 Male
School C	26 Boys	22 Girls	48	1 Male
School D	17 Boys	22 Girls	39	1 Female
School E	0 Boys	25 Girls	25	1 Female
School F	25 Boys	16 Girls	41	1 Male
School G	09 Boys	18 Girls	27	1 Female
Total	106 Boys	137 Girls	243	4 Female, 3 Male

Table 4: Sample details

A total of seven teachers, 4 females and 3 males, participated in the study. They all taught science subjects to grade 9 students. None of them had a physics background, some of them studied biology, and others studied chemistry during their graduation. Every year they were required to teach a chapter on basic astronomy to grade 9 students as it is part of their syllabus. Both students and teachers had rich cultural knowledge of several astronomical phenomena as there are many stories, rituals, and festivals around those phenomena.

Q. no.	Question
1	Every day at noon, the Sun is exactly overhead
2	The Moon does not rotate around its own axis
3	Saturn can be seen by the naked eye (without a telescope)
4	Planets which are closer to the Sun take more time to complete one revolution than the planets which are farther away from the Sun
5	Day and night occur because-
6	Seasons occur on the Earth because-
7	Which of these pictures is NOT a phase of the Moon?
8	The Moon rises from-
9	Mark the picture which shows the position of the sun, earth and moon at a full m oon
10	Which force is responsible for the Moon to revolve around the Earth?
11	The period from New Moon to Full Moon is called-
12	In what phase is the Moon on Diwali night?
13	Which is the brightest star in the night sky?
14	The asteroid belt is situated in between-
15	Which is the correct order from the smallest to the largest in size?
16	Which is the correct order from the nearest to the farthest from the Earth?
17	Which of the following objects produces its own light?
18	Which of the following is not part of our Solar System?
19	Which of the following is the name of a nakshatra (lunar mansion)?

Table 5: Details of questions used in figure 2

ANALYSIS AND RESULTS

This paper presents an analysis of students' pre and post-test data. Out of the 243 participating students, 169 students took both the pre and post-tests, so we included only 169 students in the statistical analysis. A dependent samples t-test was conducted to determine if students' understanding of astronomy improved after completing the module. We found that student performance on the basic astronomy test improved from pre-test (33.31%) to post-test (46.58%) and it was statistically significant ($p<.001$) with an effect size of 0.81.

A breakdown of the test questions that were similar showed that out of 20 questions, students' performance in 13 questions showed more than 10% improvement, performance in 5 questions showed no improvement (+ or - 5%), and performance in 2 questions showed negative improvement (approximately 10% or more). Figure 2 shows the change from pre to post-test for each question.

The pre and post-tests also had questions to probe students' attitudes and beliefs. As shown in Figure 3, students' attitudes toward science and specifically toward astronomy did change. Students reported slightly more positive views toward science after the intervention, in that fewer students strongly disagreed with the statement, "I enjoy learning science". Additionally, fewer students disagreed and more students agreed with the statement saying that science should be used when making decisions in everyday life, which suggests that students saw value in science even though some of them did not enjoy learning science. After completing the module, students indicated an increased interest in astronomy to the extent that some of them want to continue learning astronomy even after graduating from the school. More students said they would like to engage in astronomy related activities after completing the module (Figure 4). The number of students who said they did not like astronomy decreased slightly.

The module failed to have any impact on students' beliefs about the impact of astronomy on their life. At three different places, students reported that they think planets have an impact on their lives, eclipses are bad omens, or that they engage in making horoscopes and astrology (Figure 4, option D and Figure 5)

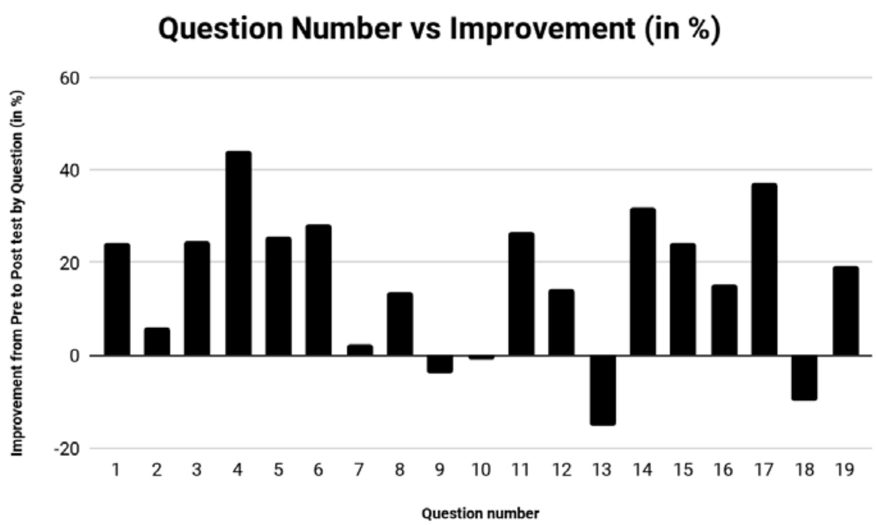


Figure 2: Question number vs Improvement from Pre to Post-test by Question. (Details of the questions are in table above)

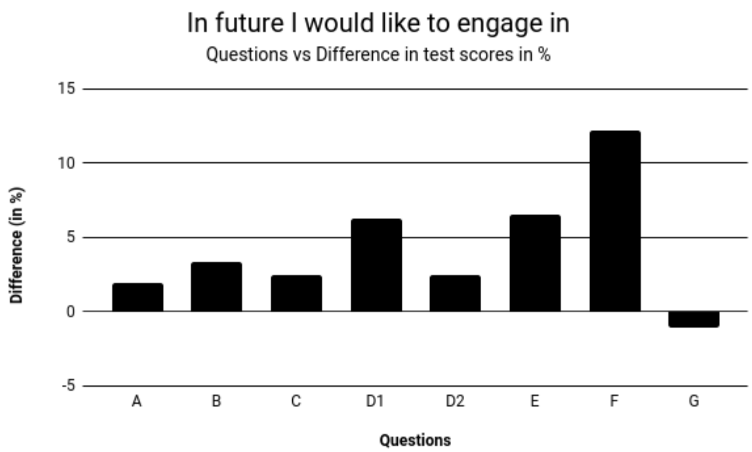


Figure 3: Students response to the following five questions regarding attitudes towards science and astronomy: A. I enjoy learning science, B. Scientific thinking should be used in taking decisions in everyday life, C. I find astronomy interesting, D. I would like to continue to learn astronomy in college (after 10th grade)

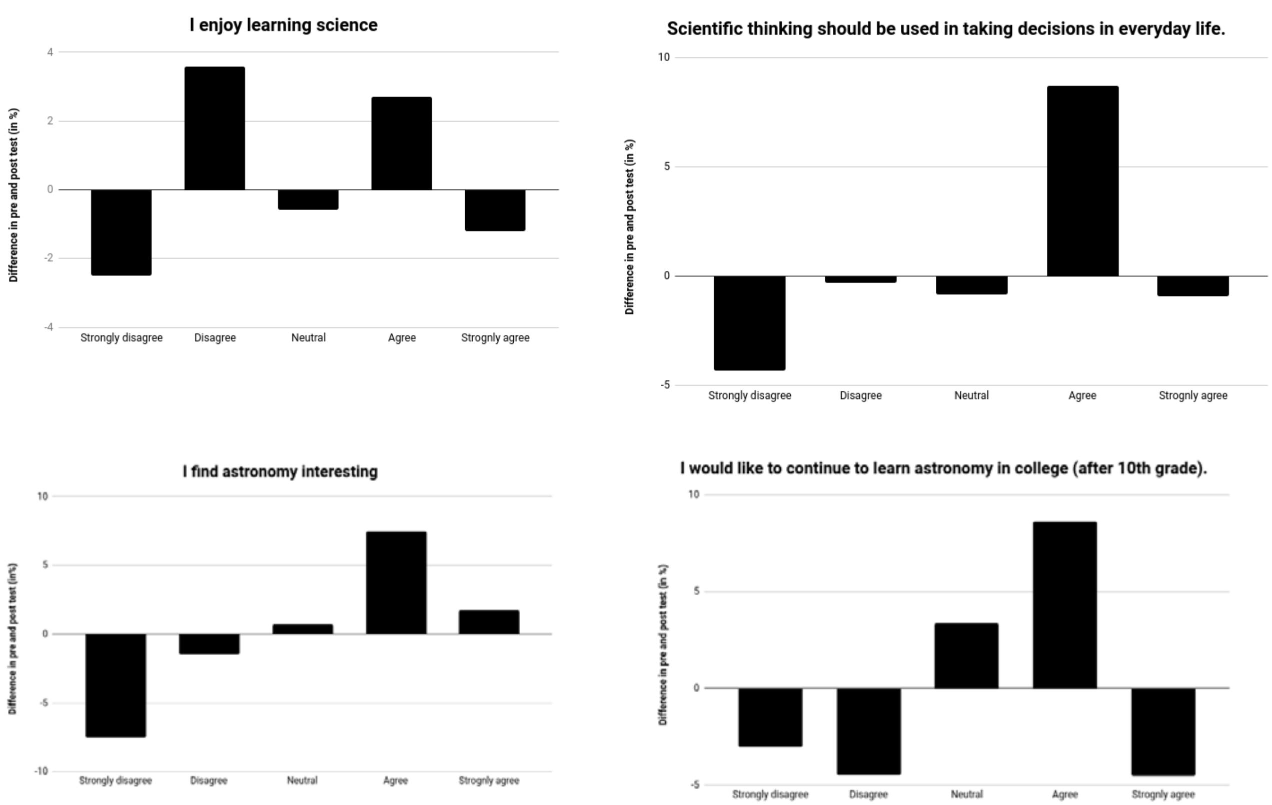
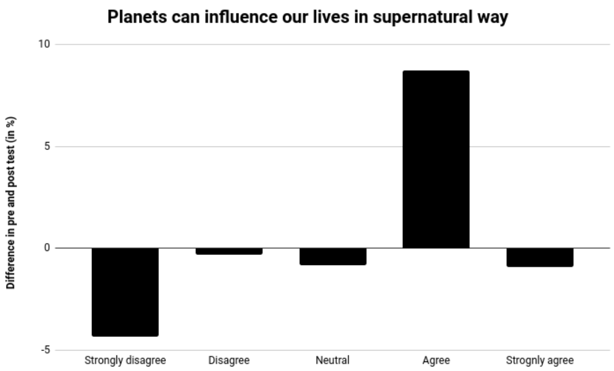


Figure 4: Students response to the question ‘ In future I would like to engage in:’. (Options: A. Observations of the moon, sun, stars and other astronomical objects, B. Learn more about different theories such as the formation of stars and solar system, C. Drawing pictures and making films about astronomy, D1. Preparing telescopes, satellites and other instruments, D2. Horoscopes and astrology, E. Doing calculations of orbits, energy etc, F. Studying how astronomy was developed in different parts of the world, G. Not interested in astronomy)



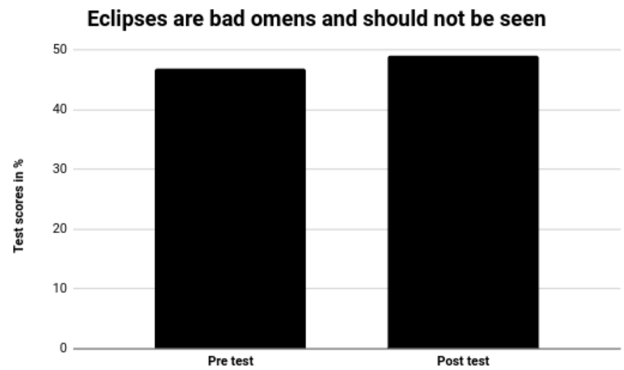


Figure 5: Students response to the following questions regarding beliefs: A. Planets can influence our lives in a supernatural way. B. Eclipses are bad omens and should not be seen

CONCLUSION AND DISCUSSION

A 'Basic Astronomy' module was designed to teach important astronomy concepts to students. The aim of this study was to investigate the impact of the module in changing students conceptual understanding, attitudes, and beliefs. A significant improvement in students' scores shows the module's effectiveness and robustness in the field. The module was also successful in changing some of the students' reported attitudes and beliefs towards science in general and astronomy. After engaging with the module, students reported positive changes in attitude toward science and astronomy, and reported increased interest in astronomy related activities. But such changes were not reported in the case of beliefs. More specifically, the beliefs which are part of the culture - the beliefs related to astrology— were not changed. It seems that such deeply held beliefs cannot be changed just by improved conceptual understanding, or change in another related belief. For example, after doing the module, more students believed that science should be used in everyday decision making but students did not view this as a conflict with making decisions related to astrology.

Lelliott & Rollnick (2010) mentioned in their extensive review that most studies in astronomy education do not refer to any particular framework. The study and other similar studies are significant because they systematically derive pedagogic ideas from an emerging framework such as embodied cognition and provide evidence of its effectiveness which in turn confirms the merit of an emerging cognitive theory. Furthermore, although many innovative pedagogies are effective in controlled settings, scaling them is challenging, particularly in disadvantaged settings. These results are important because they demonstrate that innovative pedagogies can be designed and implemented with the help of technology. It must be noted that four of the authors on this paper worked extensively with the teachers for more than three weeks to prepare them to implement this module and teachers spent considerable amount of time and efforts to improve their content and pedagogic content knowledge, but that will be the topic of another article. However, it is worth mentioning that the teachers who were initially skeptical about this new (and somewhat time consuming) pedagogy, were thrilled after going through the experience. We hope that both cognitive theories and educational technology will find practical applications through pedagogies designed for large scale implementation and the coming years will see more papers which document the challenges faced during implementation, their practical solutions and data from disadvantaged - or rather, differently advantaged - settings.

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MODELLING IN DESIGN-AND-MAKE: SYNTHESIS OF A BIOLOGICAL CELL INTO A BOARD-GAME

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Modelling is an integral part of the design-and-make experience. The translation and use of knowledge from one domain to develop a production in a different domain requires deeper engagement. This paper reports a pedagogic experiment involving social science undergraduates designing and making a board game for secondary schools students to help understand a biological (animal or plant) cell. Analysis of board games revealed two forms of engagement with modelling: abstractive and transformative. Models that captured the essential features generalisable of a typical cell into a different form of representation were identified as abstractive kind. Other cell models which extracted conceptual ideas and re-represented them into a distinctively different form, opening newer ways of imagining were classified as transformative. The study offers insights into how modelling enriches conceptual learning and exemplifies possibilities of integrating design-and-make in higher education.

DESIGN-AND-MAKE AS VALUED CONTEXT FOR LEARNING

The contemporary educational discourse aims at making school learning meaningful and engaging. The proposals for integrating design and technology (D&T) education within the ambit of school education are receiving greater reciprocation from diverse stakeholders. Design-and-make units have potentials to provide relatable contexts for inquiry and learning (Baynes, 2010; Kimbell & Stables, 2007). They provide opportunities for simultaneous immersion into knowing, doing, meaning-making and transcending knowledge across disciplinary boundaries (Khunyakari, 2019). Studies within the global (Banks & Barlex, 2014; Crismond & Adams, 2012) and the Indian context (Khunyakari, 2015) vouch for curricular and cognitive gains through an integration of design-and-make in school curricula. The learning processes involved align with naturalistic patterns of human learning rather than knowledge presented as piecemeal, isolated bodies of information. More importantly, design-and-make experiences have scope for developing creative ingenuity, empathy, critical reflection and social consciousness among individuals engaging with the learning activities.

Models and Modelling in D&T education

The process of modelling is an inseparable part of design and technology endeavours (Elmer 1999; Welch, 1998; Davies, 1996). Roberts, Archer & Baynes (1992) argue that modelling plays an equivalent role of language in the process of designing. Barlex (1991) hints at the role of model, different from physical artefact or end in itself, serving as an aid to reveal pupil's thinking. While acknowledging instrumentality of models, Liddament (1990) argues the need to distinguish use of models as 'information carriers' from those serving teaching function. Teaching, which involves supporting learners in identifying and elaborating the underlying conceptual structures, through modelling has been less researched. Smith (2001) proposes categorisation of models into three kinds, namely; *iconic* (representing a product or part of it, e.g. drawing or 3D model of kettle handle), *analogue* (diagrams using symbols to represent a system or product, e.g. electronic circuits) and *symbolic* (using abstract code to represent aspects of an existing or possible product or system, e.g. mathematical model of a bridge). Archer (in Roberts et. al., 1992, p.9) argues 'humans construe sense data and construct representations spatially and presentationally, rather than discursively and sequentially.' He asserts that 'cognitive modelling' is unique to designing, enabling one to form images in the mind's eye, and have capabilities to operate, manipulate and evaluate them.

RELEVANCE OF THE STUDY

The efforts directed towards understanding learning processes resulting from an assimilation of cross-cutting concepts are increasingly gaining recognition (NGSS, 2013). Several studies attempt to identify and underscore the connections across disciplines by inquiring into the nature of disciplinary knowledge brought to bear in a particular unit or activity. However, such a fact-finding exercise does not serve much beyond the purpose of validation. In such studies significant ideas related to practice, such as, the quality of connections made, the kind of support afforded, forms of assessment used, etc. do not become explicit. In other words, the qualitative nature of the conditions that afford learning remain hidden. For instance, the contexts that stimulate individuals to pursue a concept from across domains (of knowledge), either by morphing or radical transformation of seed ideas into meaningful outcomes in another domain (of use), are seldom investigated. Such experiences provide the necessary hooks to anchor possibilities for re-thinking about teaching. No matter how raw in their character, studies involving practice and 'pedagogic experiments' have the potential to offer valuable insights into the cognitive realm of human learning involving interactions with problem scenarios, knowledges, and collaborative action. Although experiences of D&T education for primary and secondary school students have been well documented, there are sparse reports of design-and-make at the higher education level, particularly in the Indian context. An increasing emphasis on subject specialisations and disciplinary streaming in higher education offer little opportunities for exercising the use of cross-cutting concepts. The pedagogic experiment reported in this paper invited social science undergraduates to venture around a central concept in life sciences (otherwise considered outside their domain space).

OBJECTIVES OF THE STUDY

Since the study involved teaching, the primary objective was to transact conceptual understanding of structure and functioning of biological cell and its internalisation in a meaningful way among social science undergraduates. The research objectives addressed are:

1. To investigate the worthiness of design-and-make experience for engaging social science undergraduates to think about fundamental concepts in the sciences.
2. To study the conditions and evidences structured around the design-and-make experience that provided opportunities for learning.
3. To critically examine students' work, their reflections and the resulting learning outcomes from being involved in the process.

THE STUDY

The study involved a 'pedagogic experiment' at the interface of teaching, development and reflective analysis. Social science undergraduates, after an exposure to foundational ideas around biological cell, were invited to collaboratively design-and-make a board-game that would help teach the concept of biological cell to secondary school students.

Participants

The participants were 60 students, enrolled in the B.A. in Social Sciences (BASS) programme at the University, where the author taught participants a 2-credit (30 hours of teaching), core course on Introduction to Life Sciences. The undergraduate programme had a mix of students from the arts, commerce and science streams. They represented diverse cultural and linguistic exposure, from across India. Usually participants in this programme come with a disinterest for the sciences and aim for a career in social development sector. Addressing the disinterest towards the sciences and seeking a relevance between the sciences and the social sciences in the first year of BASS poses challenges. The participants volunteered to work in 16 teams, each consisting of 3 to 4 individuals. Teams attempted to have a fair representation of genders, alignment interest in pursuing either an animal cell or a plant cell, and have at least one member who had studied biology at the higher secondary level. The criteria helped the teacher-researcher maintain some form of parity across teams. Individuals within each team engaged themselves in the task during break-time, after their class hours, and over weekends.

Nature of the engagement

The author, a teacher-researcher, has been teaching the course for the last 6 years. The data for this study is from the academic year 2017-18. The course aimed to develop an appreciation of fundamental ideas in life sciences that have contributed to the advancement of human knowledge and to the development of society. Going beyond just explaining the concepts, the pedagogic effort was to help students locate ideas within their historical contexts, relate to the processes involved in the discovery of scientific insights, and develop an understanding of the nature of socio-cultural and political influences shaping scientific endeavours. The breadth of ideas that can be potentially covered through such a course plan is exhaustive. Hence, the effort during course teaching was to revisit some salient ideas that not just brought a transformative character to the erstwhile knowledge but also reformed the approach to human thinking and understanding. For instance, uncovering structural foundations of life, biomolecules in complex functional existence, processes of transmission of characters (basic genetics) and change over generations (evolution). Through the process of revisiting ideas, course participants were encouraged to find relevance of ideas in contemporary contexts.

Process of the engagement

The design-and-make engagement was contingent on two kinds of 'knowing': (a) knowledge of the diverse board-games which can help trigger ideas and (b) foundations of structure and functioning of a biological cell. The participants were encouraged to use readily available resources, if possible, re-using waste materials in their immediate environment. As an initiation, a few visuals of board-games from different socio-historical and cultural contexts were shared. A trailer clip of the movie '*Jumanji*' added an element of fun and excitement. In the examples showcased, attention was drawn to features such as variety of materials, design elements like props, end-goal and norms of playing. The design-and-make task was situated within class discussions on the emergence of cell concept, formulation of cell theory as an explanation to structural organisation and procreation. Understanding biological cells invited participants to learn about organelle components, their structures, functional mechanisms, and develop knowledge about similarities and differences of a typical animal and plant cell. This content is very much a part of school science, but without the inclusion of history and social conditions that shaped the discovery of biological cells. Very often the school science projects demand learners (with support from adults) to make physical, 3D models of animal or plant cells with materials such as styrofoam. Such physical modelling is limited to a mere translation of information from standardised 2D, diagrammatic representation into a 3D, static, projective depiction. Such an act of reproduction, conceived as 'modelling', is celebrated as an outcome of knowledge about organelles and processes of a biological cell. In this study, modelling is understood differently. The designing and making of a board-game was not just a means to build and assess their understanding of concepts and skills but also a means to invoke and relate to their 'conceptual models'. The research followed the development of design ideas and realisation of board-games, on lines of a pedagogic structure of collaboration & communication centred D&T education, described in Khunyakari (2015). The outcome of this learning activity went far beyond communicative elaboration to serving a means for generating interest, enthusiasm and knowing intricate details about biological cells. While the end-products gave insights into students' understanding, the process of engagement opened up avenues to capture cognitive aspects of learning within collaborative environments, internalisation of concepts and their application into a different context.

Forms of data

The primary sources included portfolios maintained by each team, a write-up that included instructional manual for playing, and the production (board-game) itself. Team portfolios included sketches, drawings, raw ideas, information and details about biological cells, and worksheets. Following the data closely allowed noting transitions and evolution of ideas through the phases of design-and-make.

ANALYSIS AND FINDINGS

This findings are organised in two parts. A discussion on generic observations hints to conditions and evidences that triggered and supported learning. Elaborate description of two cases allows nuanced appreciation of learning.

(A) Generic observations

Out of the 16 teams, 11 teams chose to work on designing a board game around an animal cell while 5 teams worked on plant cell. The coinage of names indicated a metaphorical or an analogical connect. For instance, *Battle-via-cellula* (Understanding battles through/in cell), *Celluzzle* (The puzzle about cells), *Fort-o-chondria* (The granular castle). Translating knowledge of biological cells into board games required a command over concepts. The interests and exposure to scientific knowledge within each team varied. Often, the teams made copious notes about cell organelles, their structure and functioning. The collaborative nature of work allowed for an intermingling of concepts and skills. Collaborative discussions involved identifying symbolic salience of organelle functions and abstracting how this could be used during planning. Teams planned ‘making’ using sketches, texts and materials from their immediate environment. The participants personalised their board game as a ‘work of art’, translated ideas into material forms, calculated area and developed rubric for scoring the difficulty levels. Analysis of portfolios revealed prudent judgement by participants in tailored use of text for specific purposes like collating information, brainstorming ideas, planning changes, reflecting and reporting. Selective transformation or adaptation of known elements was driven by the following considerations: entry or exit points; envisaging the goal, levels of engagement and challenges in the game; sustaining more than two players; and scoring (goal-achieving) scheme. Teams consciously selected affordable and easily available materials such as sand, cardboard, erasers, nail paint, broken marble pieces, cloth, etc. They developed manuals for detailing rules, introducing components and props/pawns. Portable designs which could fold and fit in small spaces indicated explicit attention to ergonomics. Often the features of props, such as colours, shape and materials, aligned with the organelle features and their functions. Although board games have an implied necessity of a ‘board’, the ingenuity of participants reflected in varied use of cloth, cardboard and chart paper. The making involved a careful synthesis of details and decision-making. For instance, how many players can be involved in a game at a given point, how many flashcards need to be created and what could it contain, scheme for reward points, etc. The findings suggest fluid integration of knowledge and skills from across disciplines. Simultaneous and explicit attention to conceptual content, aesthetics and packaging reflected deep involvement and continual strive for quality outcome.

(B) Learning from two cases

Each case description includes inspirational ideas, articulated objective/s, and target audience. Aspects of manufacturing (material and resource considerations), rules, notations, and scoring rubrics developed form the second part. The last part has reflections on students’ work, observations about productions, and pointers that unfold cognitive aspects of engagement. A representation of plant and animal cell was deliberate, but the choice of cases was random.

Case 1: Cell Castle by Team *Trifolium* [Team 4]

Designed for children aged 12 years and above, this team worked on a board game plant cell to meet the dual purpose of education and enjoyment. The decisions to include a typical plant cell diagram and basic information on flash cards was rationalized as being age appropriate. The team drew inspiration from games like Snake & Ladders, Monopoly and Guess Who.

Unlike the other board games developed, which used either a chart paper or a cardboard sheet for making the primary surface, this team painted a typical plant cell on a white cloth (see Figure 1). The game had a maximum of 4 players, represented as 4 distinctly coloured pawns, stationed at four different places outside the cell and exhibited a colour correspondence. The board game was about taking each player through a journey of information about the various plant cell organelles. A roll of dice resulting in a score of either 2 or 5, entitled the player to pass through cell wall and cell membrane, pick Card 1, and occupy the “START” position. The player then passed the dice to the next player. No player gets an extra turn, either on getting the suitable position or even if the player gets lucky with 6 number upon rolling the dice. The player needs to wait for her/his turn and follow instructions provided on the card. Each flash card bore a number. The number co-ordinated cards had information about organelles and instructions that enabled a player to move forward in the game along the pre-determined path. The path of movement, identified as blocks, spanned the cell environment and also passed through organelles. Appropriate flash cards needed to be read aloud on reaching an organelle block. The game included suitable incentives and punishments (in the form of danger blocks that pull you back, painted red). The player succeeding in assimilating maximum information about cell organelles compared to her/his peers emerged as the winner.

Value considerations seem to shape designers' decisions, from the early stages of planning. The decision of providing information about organelle and its functioning through flash cards achieves the purpose of strengthening knowledge as well as retaining the fun component. Non-intrinsic (extraneous) values such as making the board game portable, cost-efficient, and environment-friendly influenced design of this product. In highlighting an interplay of knowledge and values in technological learning engagement, Pavlova (2005) emphasizes the need to be conscious of intrinsic and non-intrinsic values that shape design decisions. Further, Khunyakari (2019) argues that values considerations may take the role of primary generators during the process of designing. For instance, the self-imposed constraint of cost-efficiency translated into the need to reconfigure broken pieces of marbles into pawns by employing creative, aesthetic skills. Team's board game harnessed modelling to achieve representational access to abstract concept along with strengthened association and reinforcement of relevant information. Such a form of modelling that goes beyond just using a different medium for representation and focuses on extracting salient attributes, enriching information and aiding visuo-spatial thinking has been referred to as "abstractive modelling".

Case 2: *Étude Sur La Vie* (Study about Life) by Team MAD Creations Ltd. [Team 7].
A set of neatly packaged items in a box constituted the board game. The contents included a rectangular board folded along its long edge, a user manual, a guidebook for game-keeper, three sets of flash cards, box containing cell organelles, and a small box with dices and pawns (see Figure 2). The board game involving 2 to 4 players and a game-keeper, designed to unfold in three levels, aimed to assess understanding about animal cell among children aged 13 years and above. Team drew its inspiration from the games as Candyland and Bookchase.

Figure 1: Board Game of Team *Trifolium*   **Figure 2:** Board Game of Team *MAD*

The game had three levels. Level 1 invited players to roll the dice to get an appropriate score for choosing a card. Answering correctly the question on the card would establish a claim to cytoplasm (represented as circular structures covered by fine sand). A correct response would yield the packet of cell organelles, which the player needed to place on the cytoplasm in order to complete the model of animal cell. For each of the cell organelles, the game keeper would raise questions. The completion of this level takes the player to the next level. In Level 2, the player needs to roll the dice to a number to secure a molecule. The player in the next turn needs to get the right number on dice to choose the specific transport mechanism for their organelle. Since organelles have specific transport systems, getting a correct transport system is critical to the movement of the molecule across the semi-permeable membranes. If the player succeeds in achieving the right number, corresponding to the system, the pawn makes an entry to the cell system, taking the player to the last level. In Level 3, the player needs to pick up cards, one at a time. These cards contain instructions and some (negative or positive) points. For instance, a waste material card yields some negative points whereas cue card for vacuole allows the player to eliminate all waste material cards to vacuole since vacuoles in animal cells store wastes. As a result, the player would now have only positive points. The player with maximum score, among the four, would be the winner. Gradual progression across levels beginning with developing an understanding of cell components through a piecemeal assemblage in Level 1 to internalising the mechanism of transport for molecules in Level 2 to associating an understanding of form and function in Level 3, retains the dual purpose of sustaining interests and building levels of knowledge. The considerations of material cost and expenditure in making, remained with the team from the initial design until the production stage. A judicious choice of local materials, such as, papermash, clay, etc. and re-use of resources as “Old Amazon Box”, Pasta box, etc. while estimating budget and during making is suggestive of economic consideration in play design. Students’ ingenuity got expressed at various stages. For instance, in choosing a latin name for their board game to deriving the acronym ‘MAD’ from first letters of their names. Further, the game architecture used materials that capture organelle characteristics, colour coded scheme, and scoring rubric that symbolised aspects of organelle functioning. For instance, in Level 3, if a player gets a lysosome in her/his card, s/he must keep her/his pawn outside the cell and go back to Level 2. Participants’ conscious use of rules aligned with conceptual understanding of processes in animal cell functioning. Such an extension of knowledge to model the movement of a biomolecule across organelles within cell is an exemplification of transfer of knowledge. Haskell (2000) argues the need for creating opportunities that necessitate transfer of learning by recognising and extending opportunities of engagement to novel contexts and situations.

The norms set for fair play are critical to any board game. Analysis of these reveal the degree to which human actions were anticipated. Hence, rules of game and the scoring scheme together provided the framework for optimising cognitive engagement during play activities. For instance, an anticipation of a limited number of cards as cues made participants frame two constraints as rules. The first constraint was to read the cue card quietly and not share it with the other player. They could, however, talk aloud the answers. The time limit of two minutes per question served as the second constraint. Both constraints demanded a continual, focused engagement of players. Serious attention to details was noted not just in designing the product, but also in its packaging. Symbols for handling, the bar code and the label of manufacturing, all brought a professional character to the finished product. The team’s use of modelling to gain a focus on conceptual ideas by re-representing existing understanding into distinctively different forms thereby opening scope for questioning and challenging ideas and initiating search for deeper knowledge has been referred to as "transformative modelling". Through modelling, this team attempted to surpass the goal of strengthening or associating information to creatively recasting the content in a manner that renews or alters possibilities of thought, invoking a deeper knowledge of cell.

CONCLUSIONS AND THE WAY FORWARD

The pedagogic experiment invited social sciences undergraduates to collaboratively design a board game as a means to revisit cell concept and develop context for extending understanding. In conventional teaching, knowledge about cells is packed as information. Designing a board game presented participants with an opportunity to 'model' understanding and balance learning with fun. Participants' engagement with design-and-make of board games, without an orientation or exposure to principles of creating board games, elicited two kinds of modelling, which have been referred to as abstractive and transformative modelling. Case 1 exemplifies abstractive modelling where the team seemed to have used modelling for representational access along with reinforcing the relevant information. On the other hand, Case 2 represented transformative modelling, where the team's effort was on re-representation into an altered form that explored conceptual ideas and affording scope for operating on knowledge and refining it further. Analysis of the varied associations related to the processes of modelling in the context of this study also hints to a complex interplay of intent and knowledge, which needs to be pursued further. The context of play allowed exploration of a variety of board games, some of which have deep-seated, cultural histories. Although the dimension of culture has not been focused in this study, the data suggest the role of cultural exposure as an influence on design development. Tapping the experience for uncovering alternative conceptions related to understanding cells and mental models that participants operate upon would be an interesting dimension of inquiry that can be pursued further.

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