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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

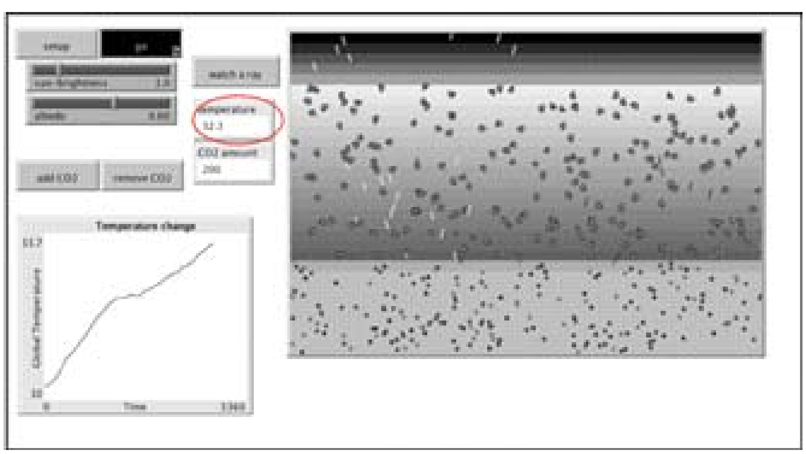


Figure 1: Climate Change Simulation

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

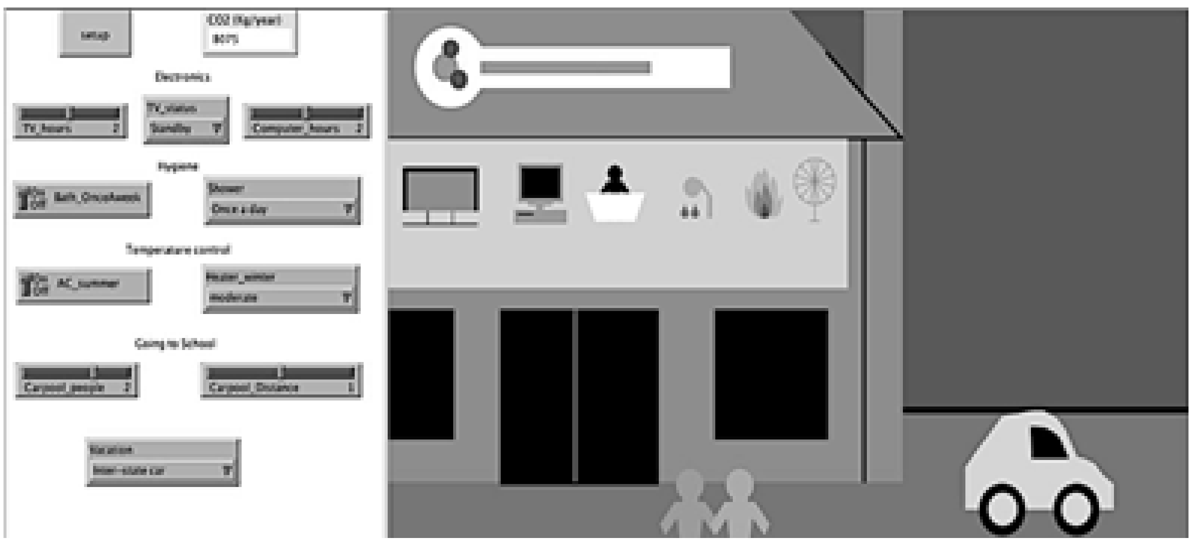


Figure 2: Carbon Calculator

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."

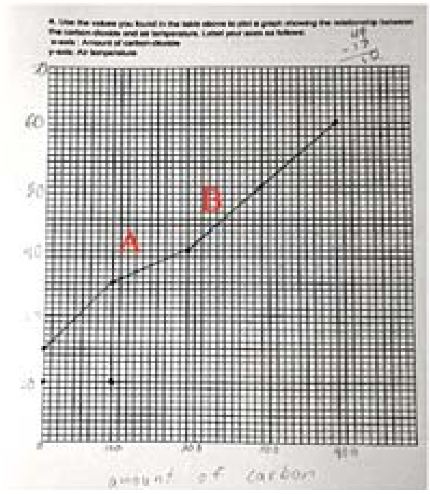


Figure 3: Ani's graph representing the relationship between carbon-dioxide and air temperature

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

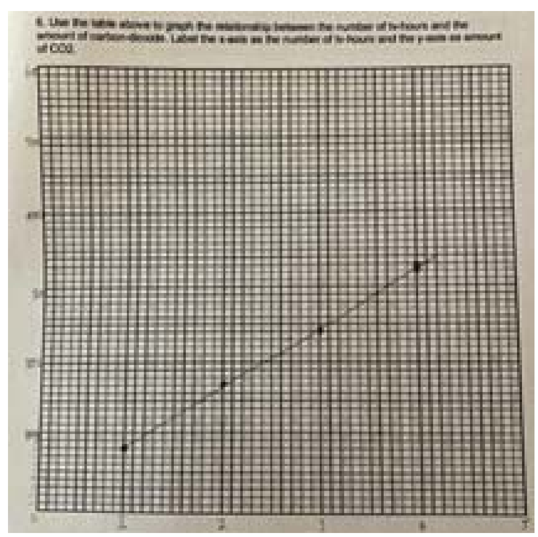


Figure 4: Amber's graph expressing the relationship between TV_hours and carbon-dioxide

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

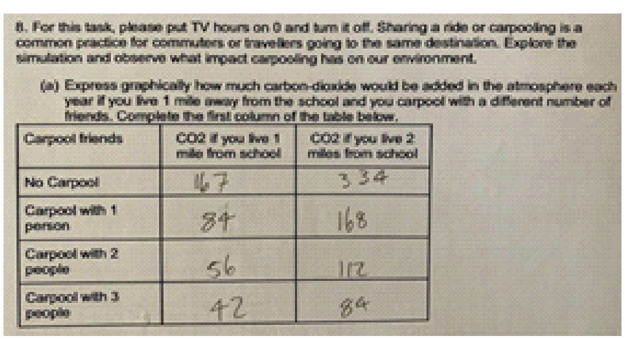
Another activity in the Carbon Calculator simulation asked the students to explore the covariational relationship between the number of people carpooling and the amount of carbon-dioxide being released. Like the TV_hour activity, here as well students modified the number of people carpooling by dragging 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

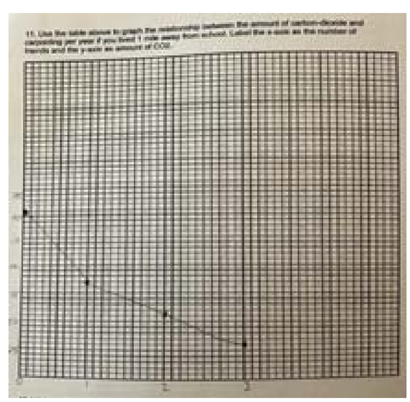


Figure 5: Amber's graph expressing the relationship between carpooling and carbon-dioxide

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.

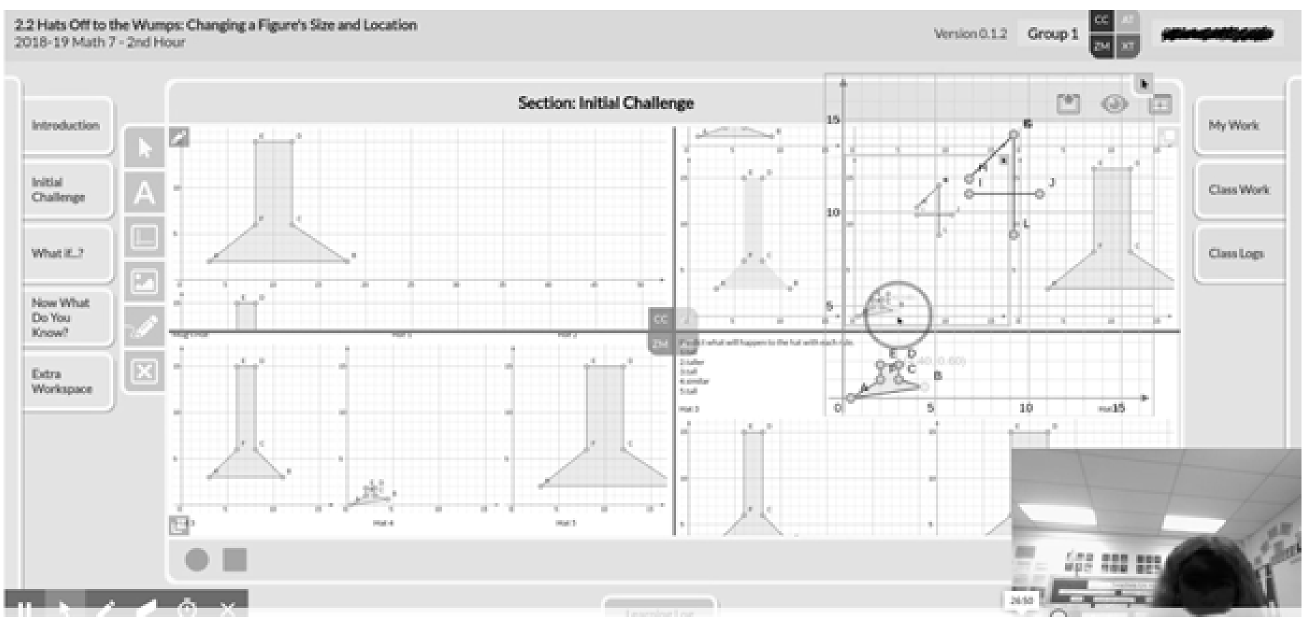

Figure 2: Screenshot of a student collaborating with other group members

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 ($\chi^2 = 302.14$; $p < 0.00001$).

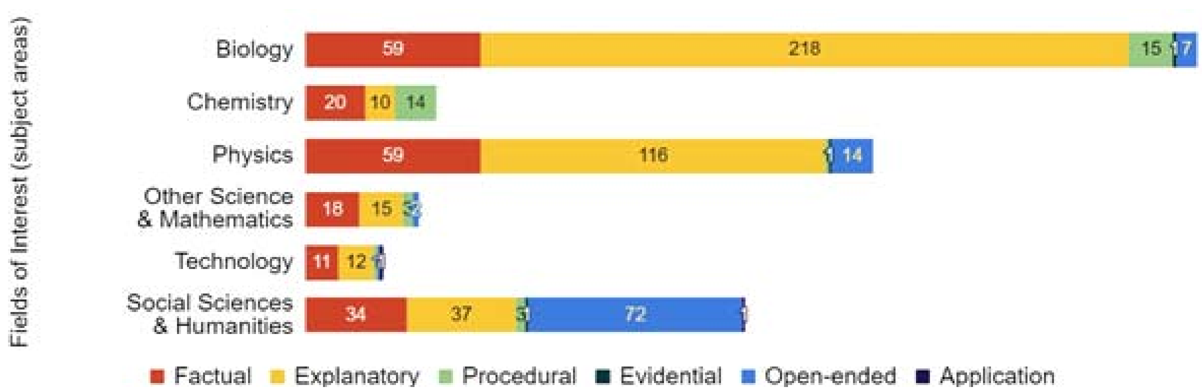

Figure 1

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/

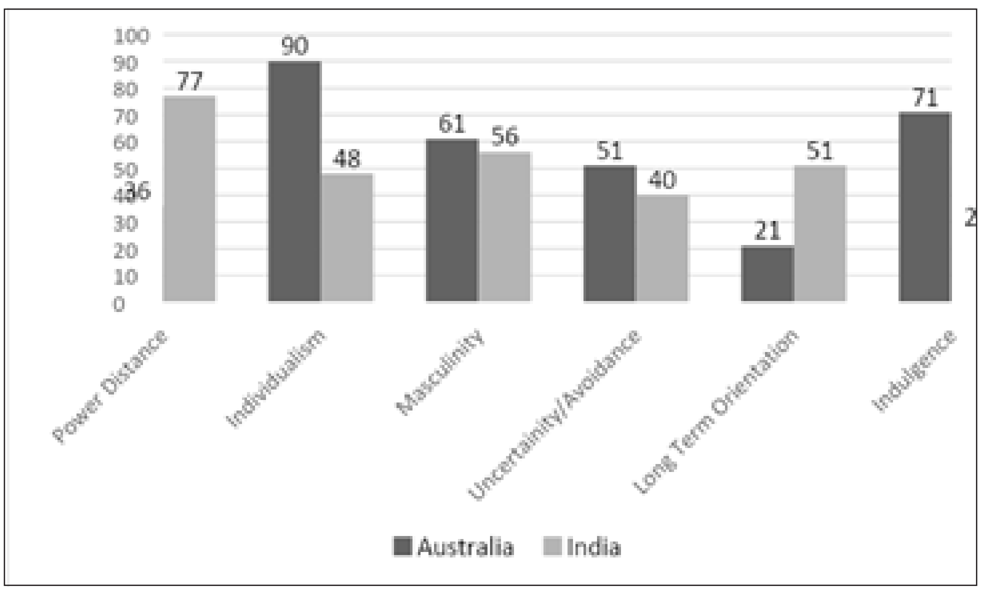

Figure 1. Australia-India country comparison (Hofstede, 2019)

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.

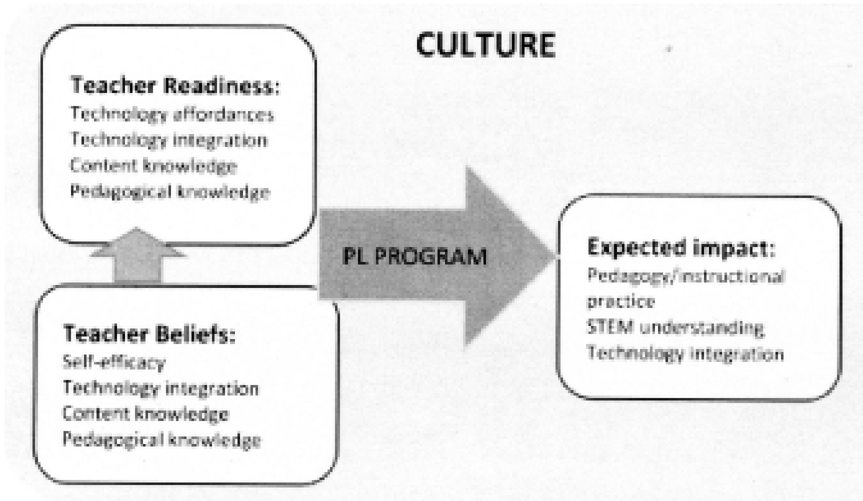

Figure 2: The program's framework

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.

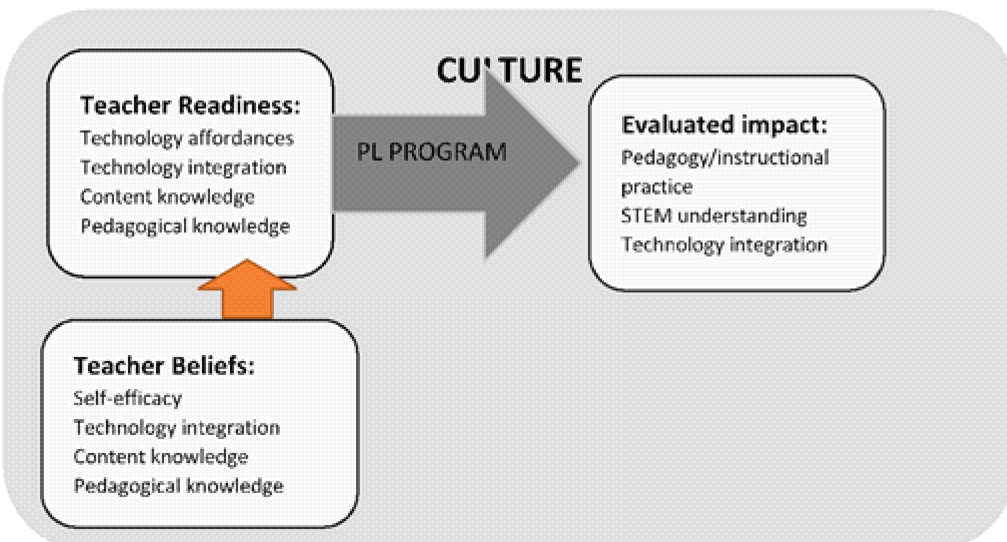

Figure 3: Bridging the gaps

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.

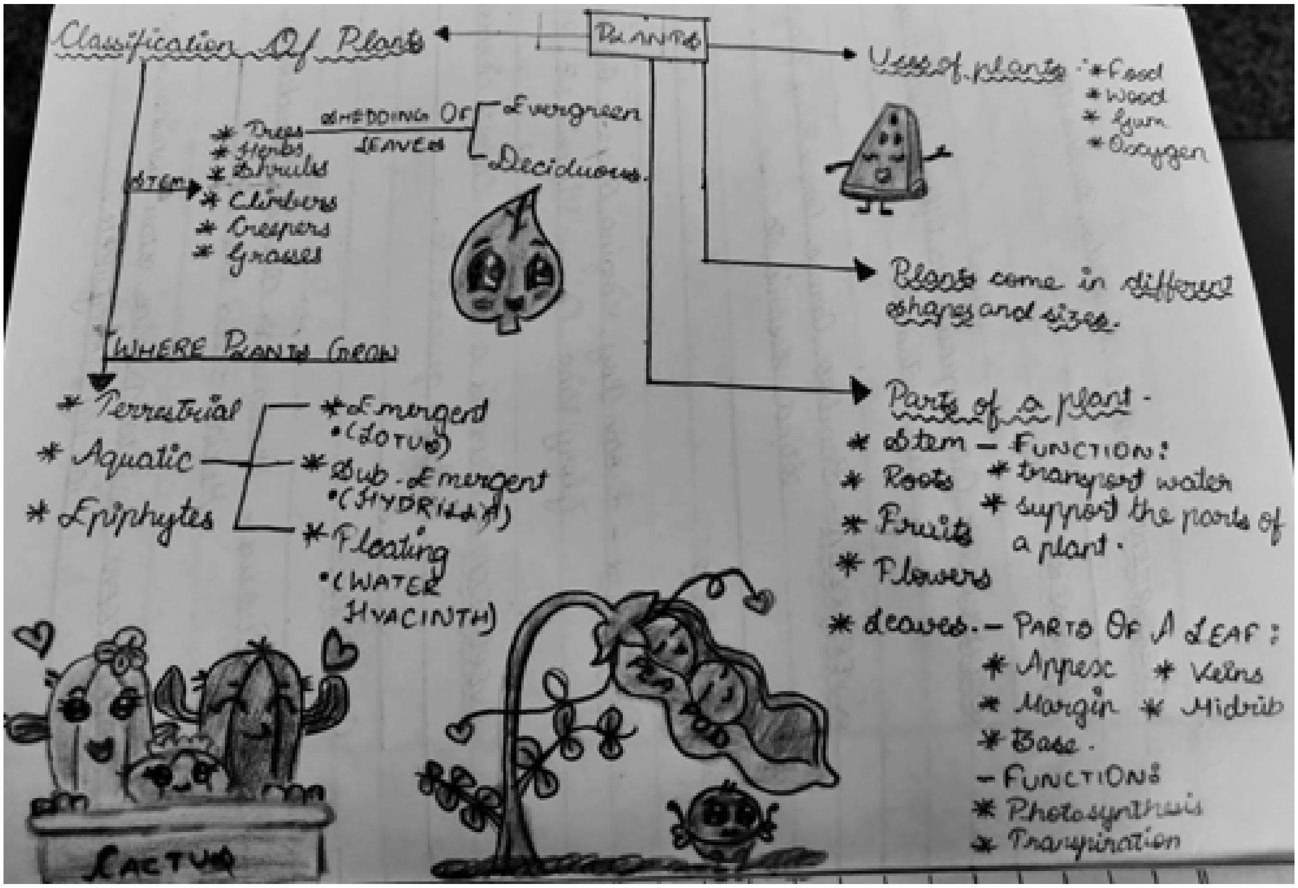

Figure 1: A Mindmap on the lesson ‘Plants’ done by student M

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 $m: B \rightarrow A$ 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*).

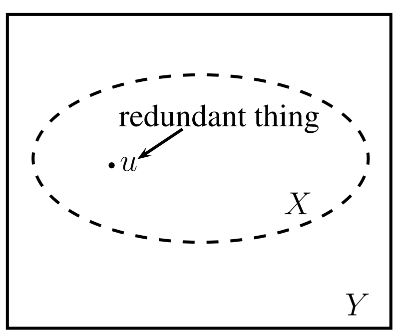

Figure 1

Intended Conjecture: A superset of a linearly dependent set is linearly dependent (*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 a smaller set also has no redundant thing (*source domain statement*).

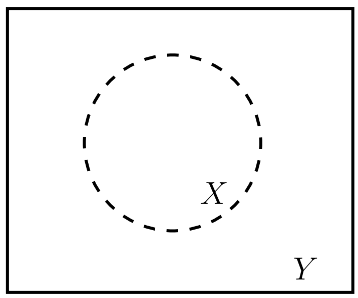

Figure 2

Intended Conjecture: A subset of a linearly independent set is linearly independent (*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? S is linearly independent.

(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? $S \cup \{u\}$ is also linearly independent.

(d) If S has no redundant thing, and if α is not an element of span S, then $S \cup \{\alpha\}$ has no redundant thing (fill the blank with details about the whereabouts of α) (*source domain statement*).

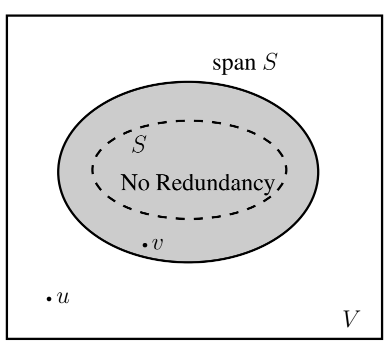

Figure 3

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.

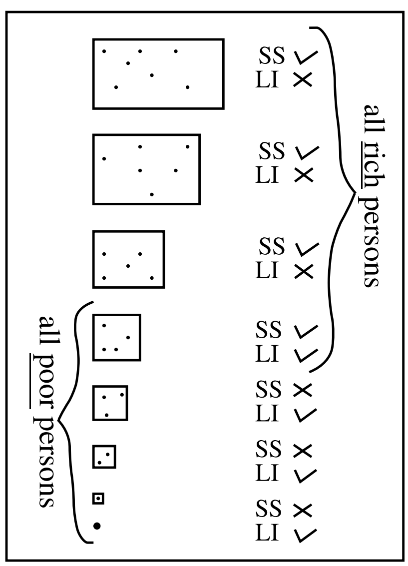

Figure 4

(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.

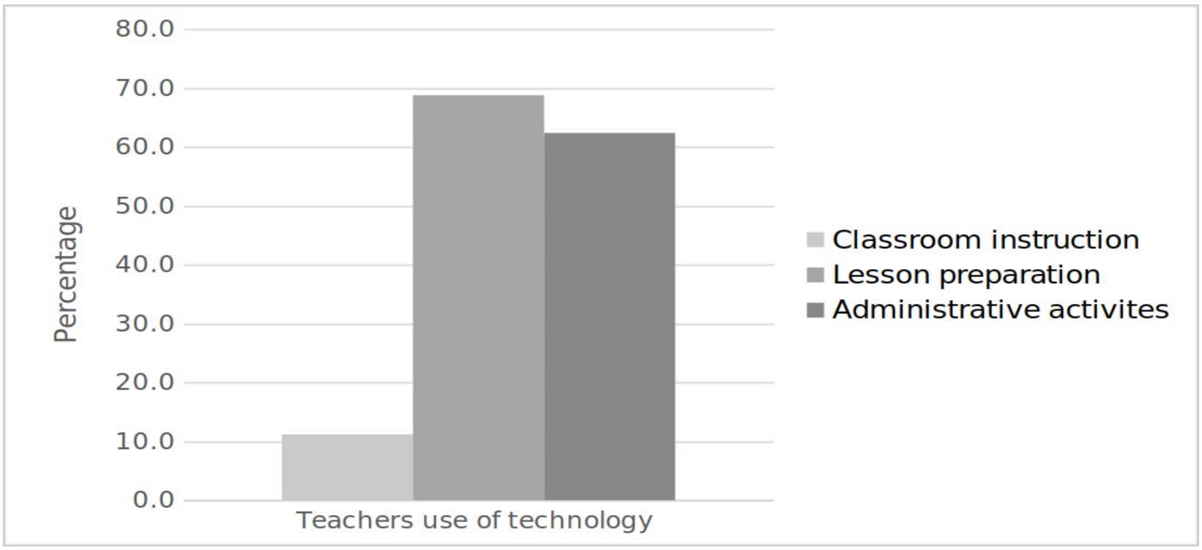

Figure 1: Mathematics Teachers' Use of Technology

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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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.

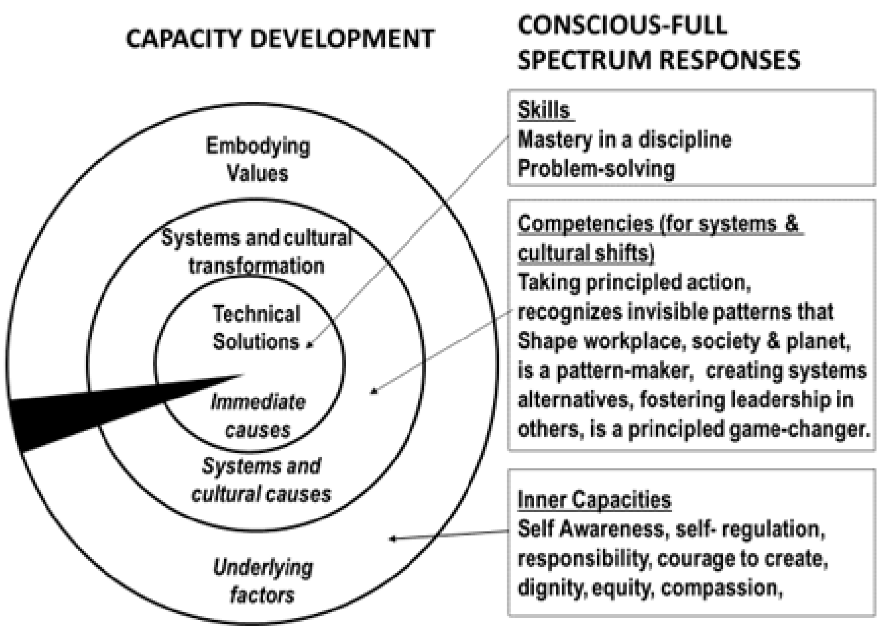

Figure 1: Capacity Development for sustainable results at scale.

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.

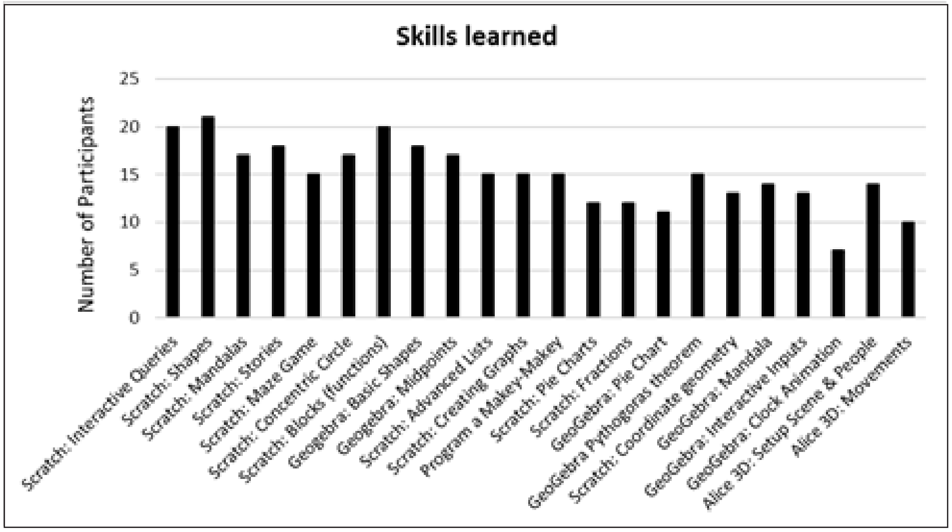

Figure 2: Skills vs the number of participants who felt they acquired them.

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.

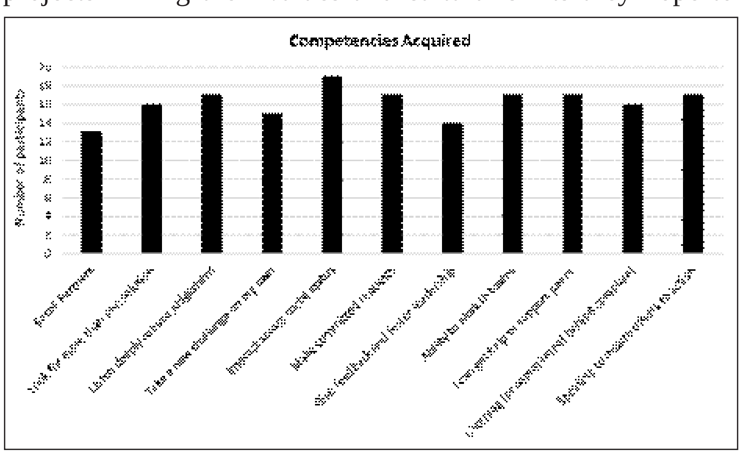

Figure 3: Competencies and number of participants who felt they had acquired them

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.

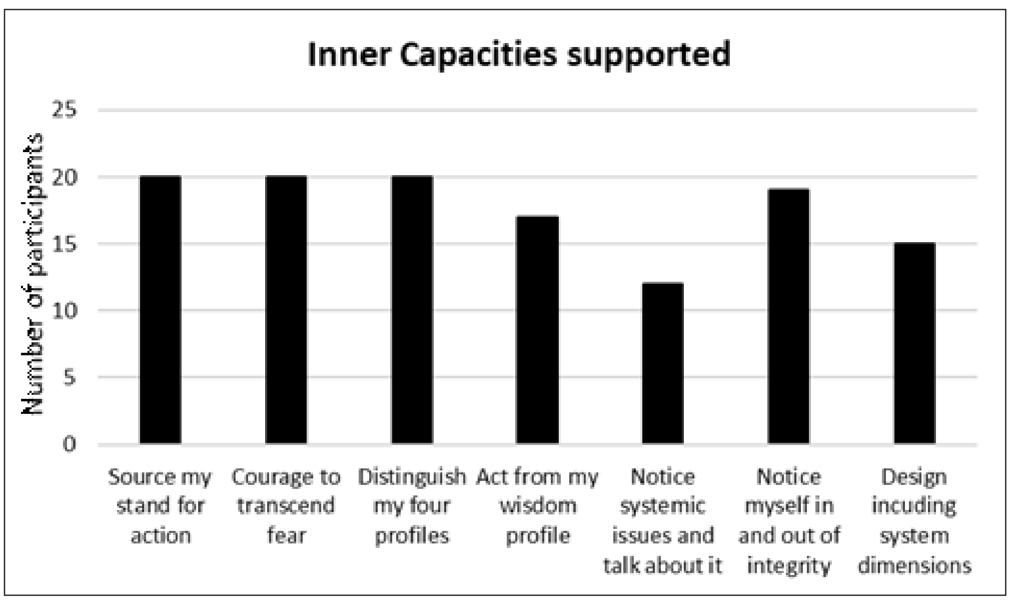

Figure 4: Inner capacities and the number of participants who believed they were able to exhibit it through the workshop

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.

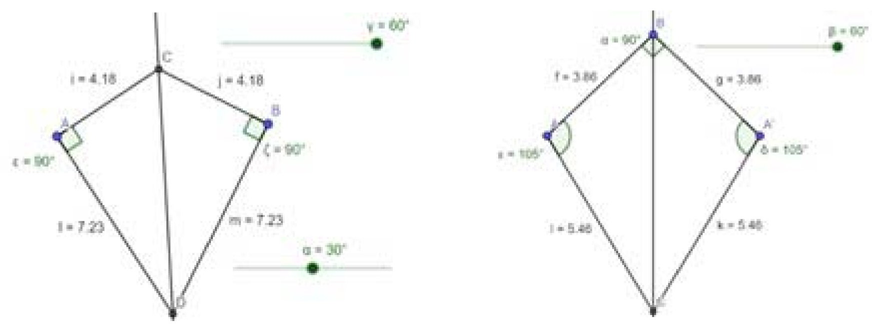

Figure 1: Right angles(s) in Convex Kite

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.

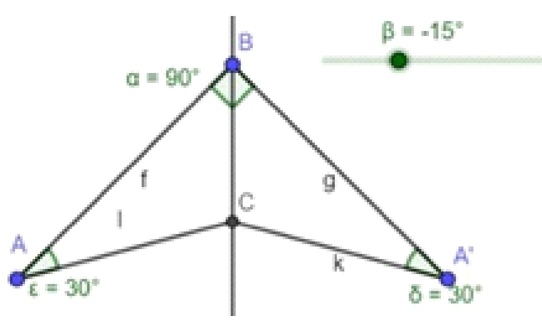

Figure 2: Right angle in Concave Kite

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.

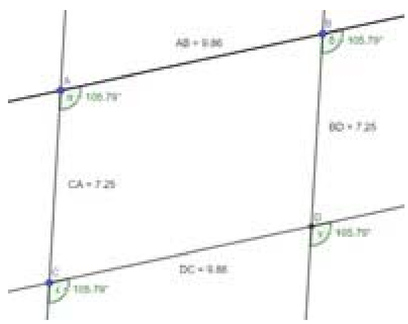

Figure 3: Definition 1

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.

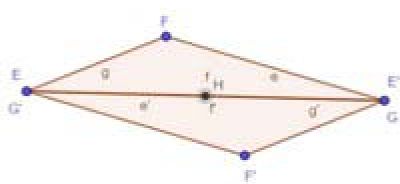

Figure 4: Definition 2

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.

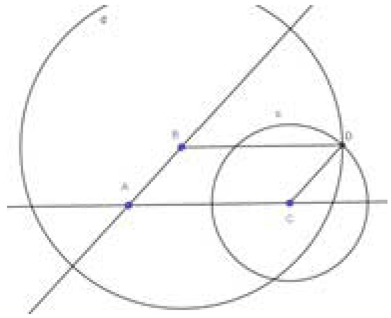

Figure 5: Definition 3

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.

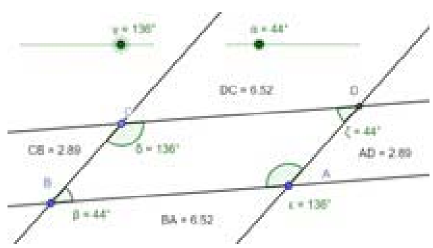

Figure 6: Definition 4

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.

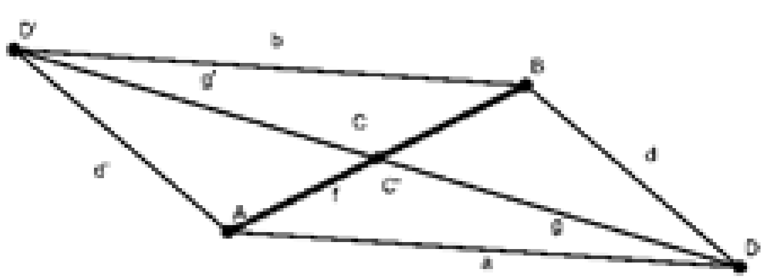

Figure 7: Definition 5

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.

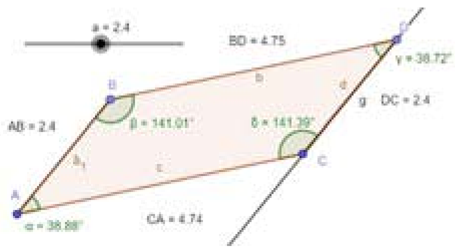

Figure 8: Definition 6

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.

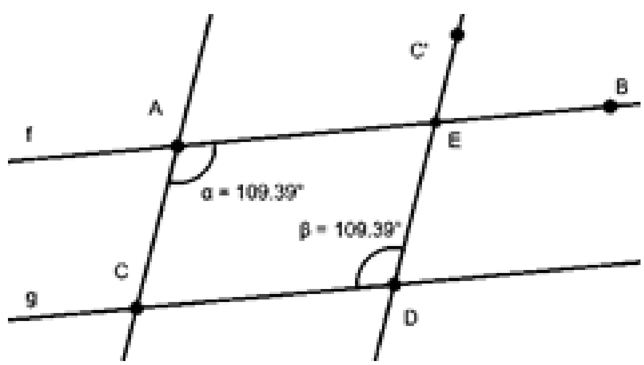

Figure 9: Definition 7

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.

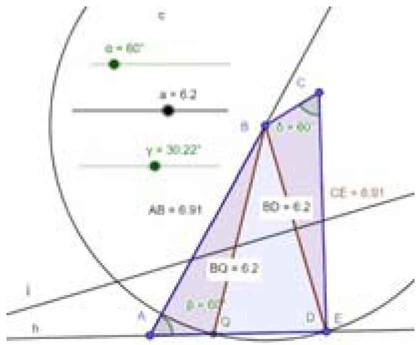

Figure 10: Definition 8

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):

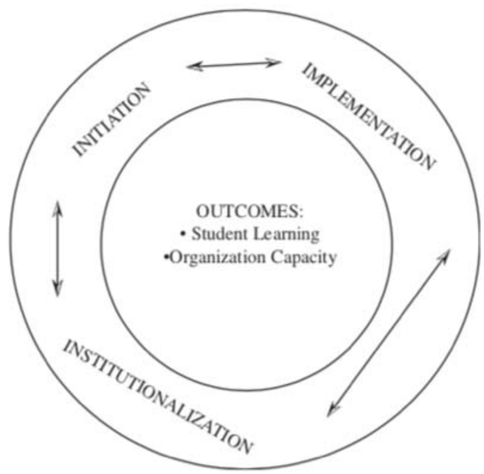

Figure 1: A simplified overview of the change process (Fullan, 2007)

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)

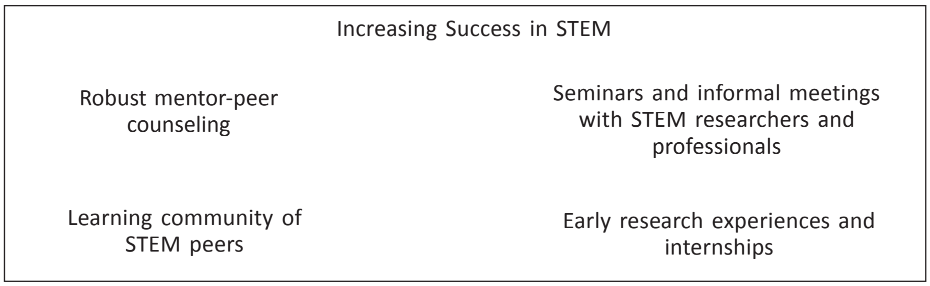

Figure 1: A model for supporting students for success in STEM

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,

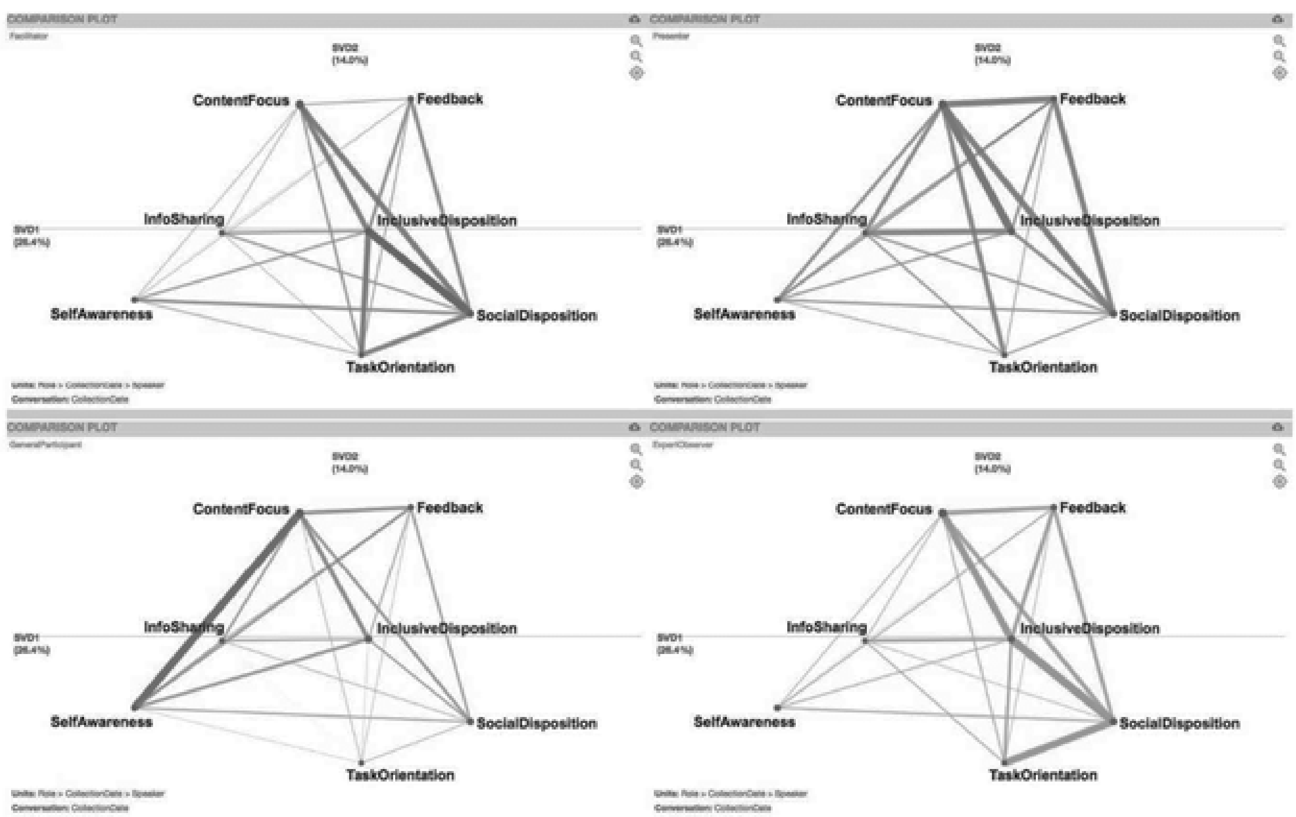

Figure 2: Discourse patterns demonstrated by different roles in IC4 online global meet-ups in 2017. The ENA models show how each role exhibited different patterns that are distinct from each other

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-

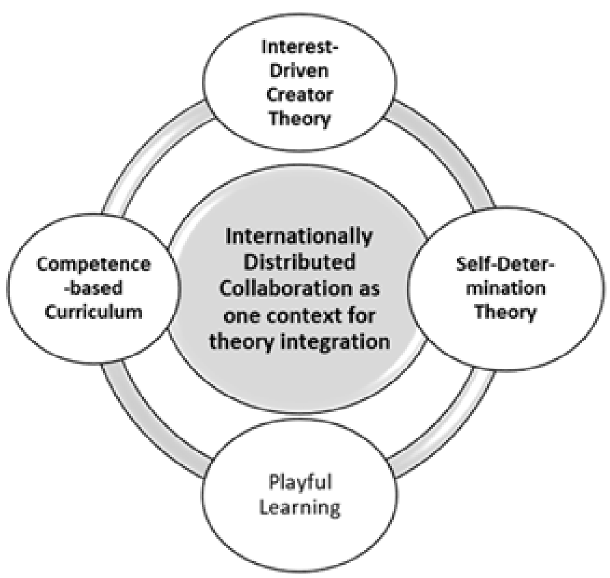

Figure 4: Research in Internationally Distributed Collaboration (IDC) can serve as a venue for synthesis and integration of important and emerging theoretical frameworks relevant to future education practice

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.

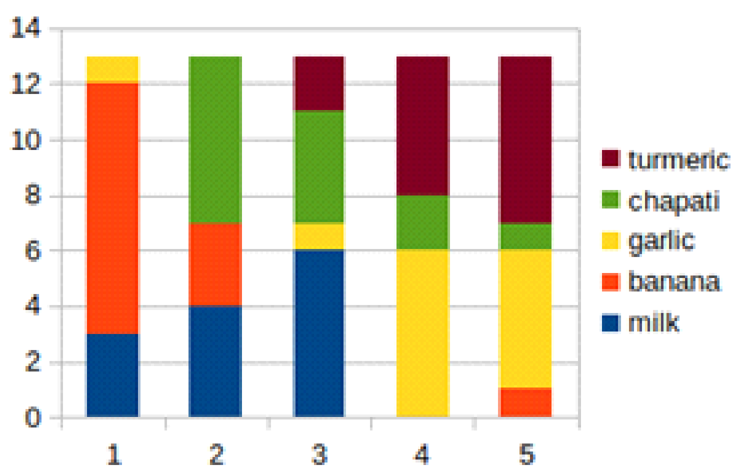

Figure 2: Graph representing students' responses in arranging picture cards. X-axis: position of food card with reference to their shelf life, indicating least shelf life to longest shelf life, Y-axis: Number of responses for that position.

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.

ACKNOWLEDGEMENTS

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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.

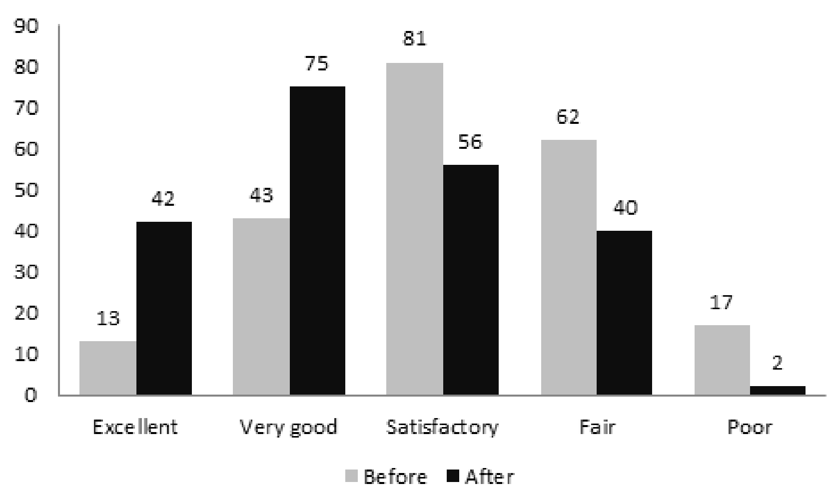

Figure 3: Rate yourself on the basis of your knowledge of application of mathematics in day to day life

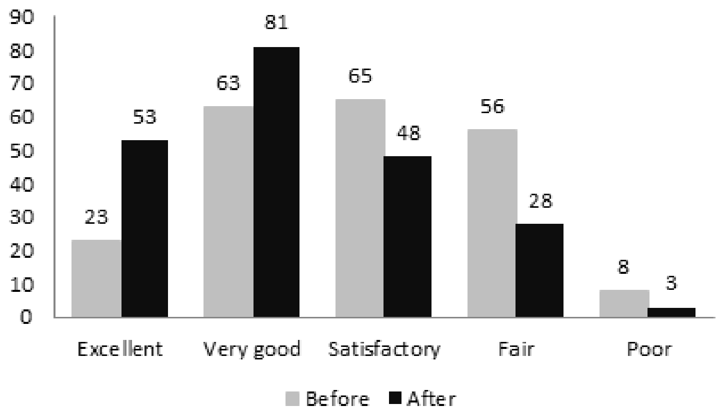

Figure 4: Rate yourself on the basis of your knowledge about connection of mathematics with other subjects

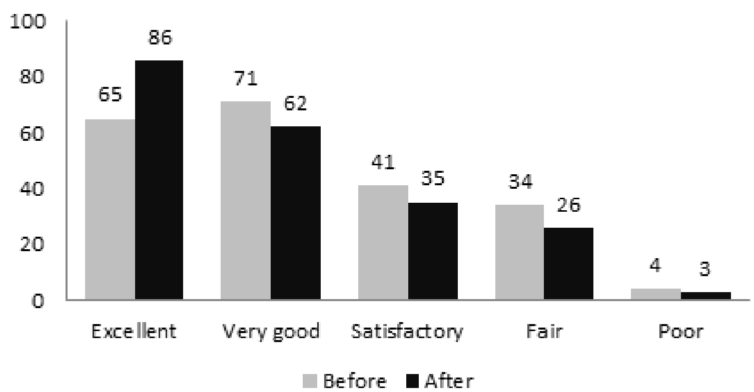

Figure 5: Rate yourself on the basis of your interest in learning mathematics

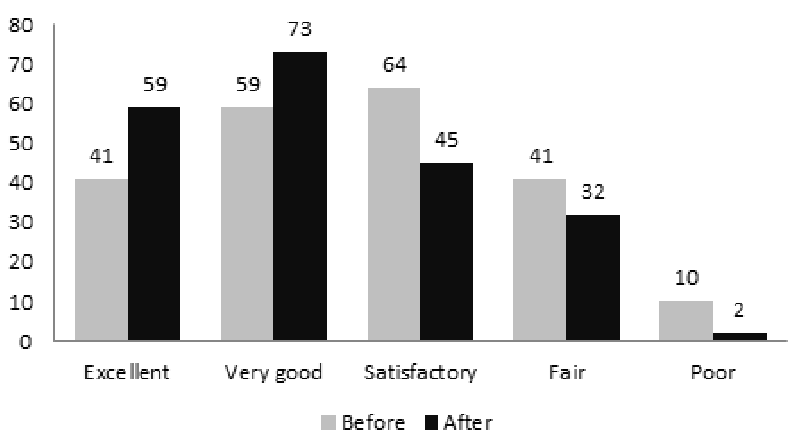

Figure 6: Rate yourself on the basis of your interest to find applications of mathematics

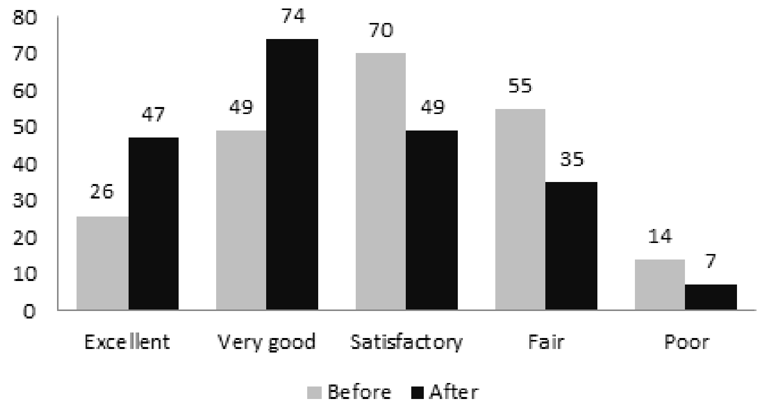

Figure 7: Rate yourself on the basis of use of internet in finding applications of mathematics

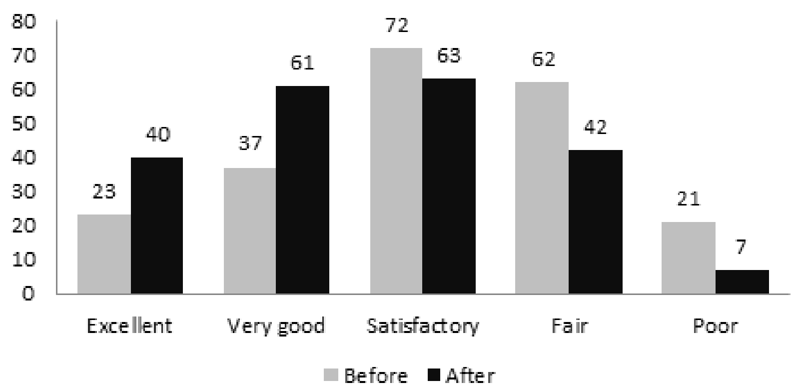

Figure 8: Rate yourself on the basis of your interaction with other world about applications of mathematics

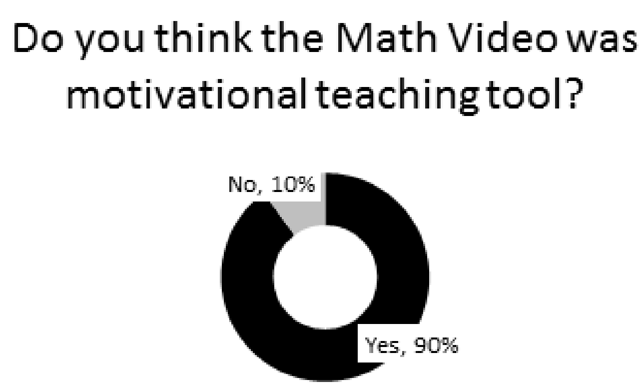

Figure 9: Math Video (WEM) as a Motivational Tool

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.

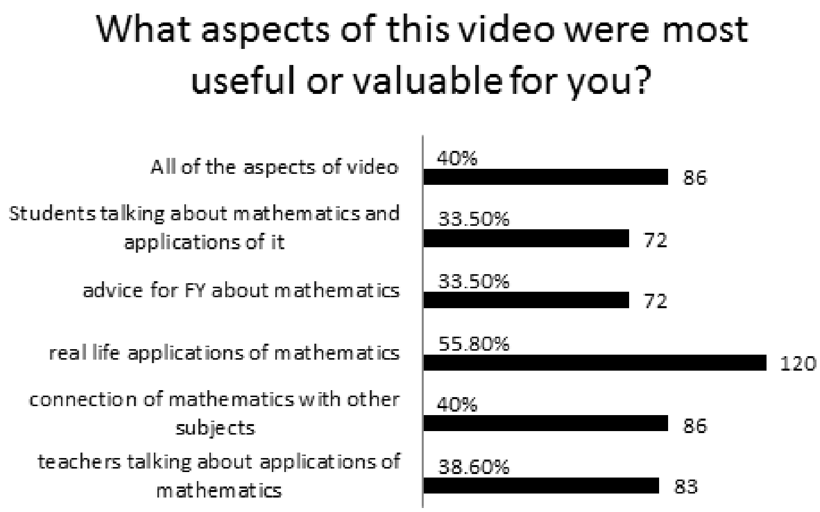

Figure 10: Overall impact of WEM

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

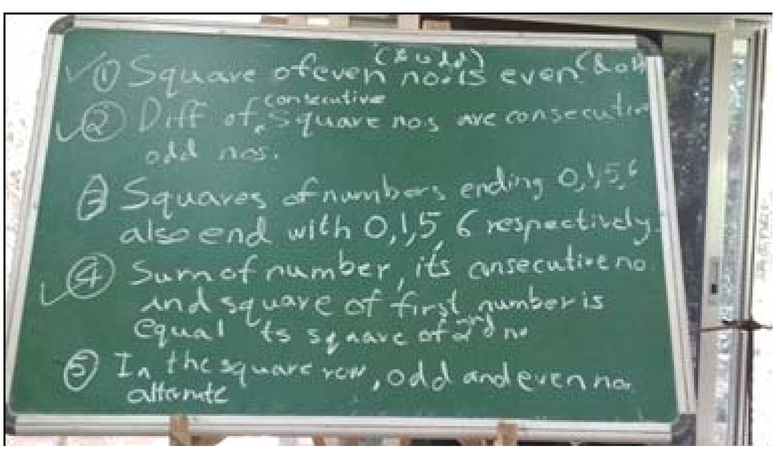

Figure 4: Some examples of students’ conjectures

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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