Strand 4

Discipline-based Education Research with Emphasis on Undergraduate Science Education

PARTICLE IN A CONFINING POTENTIAL: DEVELOPMENT OF CONCEPT INVENTORY AND IDENTIFYING STUDENTS ALTERNATIVE CONCEPTIONS

Sapna Sharma[1]*, P.K. Ahluwalia[2]
[1]Department of Physics, St. Bede's College, Shimla, India
[2]Department of Physics, Himachal Pradesh University, Shimla, India.
sapnasharma228@yahoo.com

The problem of a particle in a confining potential in introductory quantum mechanics is one of the starting points beyond Bohr model to mathematically explore how quantization arises and how with each quantized level a corresponding wave function can be attached via the solution of Schrodinger equation explicitly. This problem offers a wonderful opportunity to identify alternative conceptions of students as they make a transition from the world of deterministic classical mechanics to the world of probabilistic quantum mechanics and start seeing its efficacy in explaining phenomenon at the microscopic level. The effort is to take students from alternative conceptions to physically correct concepts. In this paper, we present the developed concept inventory for a particle confined in a box with rigid walls limited to one dimension. The results of the implementation of the inventory are compared with an expert view for each of the question items validated and tested for implementation. Concept inventory is designed and tested at the undergraduate, Bachelor of Science (B.Sc.) level students, who study these concepts not only within quantum mechanics but also in the solid-state physics course each of credit 4, during their three year, six-semester programme.

INTRODUCTION

Quantum mechanics is a physical theory, which has brought a paradigm shift in the understanding of the matter at the microscopic level, and has made us understand the real world. It is as relevant in the macroscopic world as in the microscopic world, because laws of classical physics follow from the laws of microphysics. It comes up with a good useful theory, which makes physical interpretations plausible and understandable by offering means for quantitative interpretation of experimental observations ((Hadzidaki, Kalkains & Stavrou, 2000; Ashcroft & Mermin 1976; Mott & Jones 1958). It is without doubt a key to understand the fundamental structure of matter, which is a collection of large number of microscopic particles (10^{23}). Even during the study of courses such as solid state physics course learners' come across application of various concepts drawn from quantum mechanics (Kittel, 1985). In 1970, Richard Longini in his book *introductory quantum mechanics for the solid state* (Longini, 1970) underlined the importance of basic ideas of quantum mechanics for atomic binding and for solids. However, the foundation of quantum mechanics is probabilistic in nature requiring epistemological issues, which need to be addressed for converting beliefs steeped in classical mechanics to beliefs of the expert regarding quantum mechanics (Styer, 1996) to appreciate its real life applications which has influenced deeply the technological advances made in the 20th century.

A number of conceptual surveys/inventories in different physics domain, to identify the alternative conceptions have been designed and developed by physics education researchers ((Hestenes, Wells & Schwackhammer, 1992; Thortron & Sokoloff,1998; Maloney, O'Kuma, Hieggelke, & Heuvelen 2001; Krause, Decker, Niska, Alford, & Griffin, 2003; Richardson, Morgan, & Dantzler, 2003; Sharma & Ahluwalia, 2015) to as certain alternative ideas held by the learners which are entirely different from the expert view. Sometimes these alternative ideas form a significant barrier to learning correct expert view. In recent years, many studies have been undertaken on students' understanding and alternative conceptions held in quantum mechanics (Belloni, Christian, & Cox, 2006; Zollman et al., 1999; Zollman, Rebello, & Hogg, 2002; Singh, 2007; Singh, 2001; Muller & Wiesner, 2002; Bao & Redish, 2002, Cataloglu, 2002; McKagan, Perkins, & Wieman, 2010; Wuttiprom, Chitaree, Soankwan, Sharma, & Johnston, 2006, 2008; Sadaghiani, 2005). The exploration and research of such alternative conceptions can help teachers and researchers to know how learners perceive particular knowledge and justify their inferences. The information of alternative conceptions can also be helpful for teachers in deciding their teaching strategies to improve student understanding of the concepts.

In this paper, the development of a concept inventory of quantum mechanics for undergraduate, Bachelor of Science (B.Sc.) three years degree course has been discussed. Further, in the paper students' some alternative conceptions identified on one of the theme of concept inventory is presented.

METHODOLOGY USED

The methodology used for developing the concept inventory on quantum mechanics is explained below. The tool (consisting of only one theme "particle in a box") discussed in this paper is a subpart of the concept inventory (Kaistha, 2014) consisting other themes as well. Table 1 provides the concept profile of this theme which can act as a prerequisite for solid state physics course also.

i. Identification of concept domain

Different quantum mechanics concepts which are required to understand various topics of solid state physics course were identified first.

ii. Identification and defining of themes

After identifying the concepts of quantum mechanics, six themes (i) basics of quantum mechanics (ii) wave particle duality (iii) uncertainty Principle (iv) wave function and Schrödinger equation (v) particle in a box and (vi) Tunneling Effect were selected for the concept inventory.

iii. Delphi Study

To validate the above defined themes a research technique called Delphi Study was used. It involved interactions and discussions with the experts of the concerned field. In this case, the process was carried out with almost ten faculty members of physics department of local undergraduate colleges in Shimla, and one Engineering Institute of Shimla.

iv. Interactive session with students

An interactive session was carried out with the third year students of B.Sc. three years degree course. These students had earlier gone through the quantum mechanics and solid-state physics courses. This session helped us to understand the students' difficulties and ideas in the understanding of quantum mechanics and solid state physics courses and hence designing of the questions.

v. Drafting of multiple choice type questions

The drafting of multiple choice question items of the concept inventory was done by consulting various textbooks and other resources. To get structural validity a draft of concept inventory was sent to 15 experts all teachers in colleges or universities all over the country to check mark and point out any

- deviation from concept specificity of the question item
- ambiguity as regards physical concept involved
- ambiguity of wording and diagrams in the sent items
- choices/ alternative options, which in their opinion are not good distracters etc.

vi. Validity (Item Analysis)

To check the quality of each question item, *item discrimination test*, *item difficulty test* and *point biserial coefficient test* were performed on each question item.

vii. Reliability (Test Analysis)

To check the reliability of the whole test, Cronbach Alpha coefficient test and Ferguson Delta test were performed (Kaistha,2014) The instrument developed on alpha coefficient 0.92, which seemed to be reliable (Nunnally, 1978).

MODE USED

As an exploratory testing, the assessment tool (Appendix A) was administered in the form of pre-test and post-test at the beginning and at the end of the quantum mechanics course to undergraduate students. This course was taught to them in the second year of their three years degree (B.Sc.) program by traditional classroom methodology. 128 undergraduate students (UG), studying in four different undergraduate colleges of Shimla, affiliated to Himachal Pradesh University, Shimla, India, participated in it. The tool was also administered to 25 postgraduate (PG) students, studying in Physics Department, Himachal Pradesh University, Shimla. The PG students study an advance course on Quantum Mechanics in their master's program. Along with it the tool was also administered to 50 teachers, teaching physics in the different colleges all over the country (India), and undergoing a three weeks refresher course in physics, at Academic Staff College (ASC), Punjab University Chandigarh, and Academic Staff College (ASC), Himachal Pradesh University, Shimla. To PG students and to the teachers the test was administered only as pre-test. All the target group members were given two weeks advanced intimation for the administering of the test and they took almost an hour to finish the test.

Theme	Concept Profile: Topics of Solid Sate Physics course in which concept(s) is/are of themeused
Particle in a box	Free electron theory of metals, Somerfield's quantum theory of free electron gas model, lattice vibrations, harmonic oscillator, analogy of phonons with photons, band theory of metals and nano science

Table1: Concept Profile of theme-'particle in a box'

DISCUSSION AND ANALYSIS

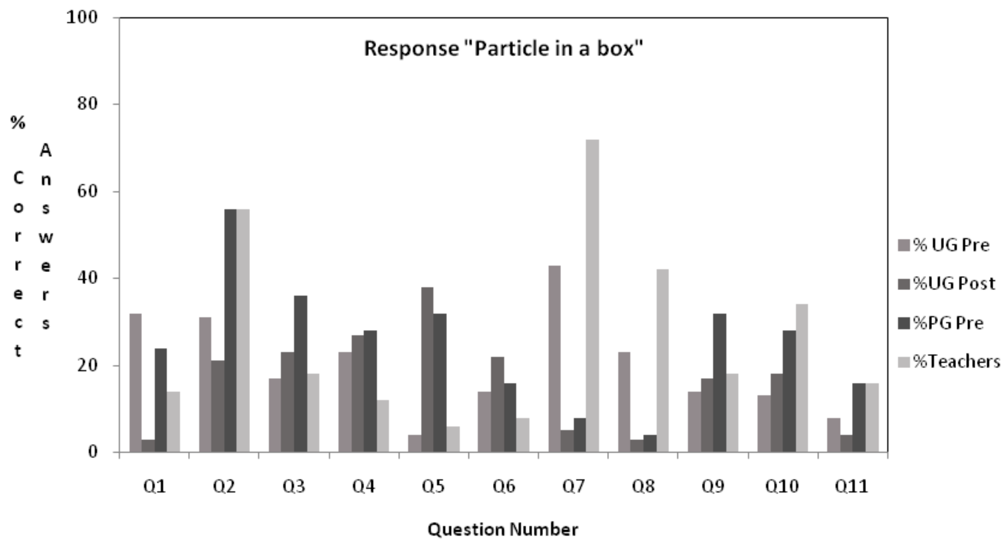


Figure 1: Response of UG, PG students and Teachers on Theme (Particle in a box)

Particle in a box

Particle in a box is a very interesting model in Quantum Mechanics which is mainly used as a hypothetical example to illustrate the differences between classical and quantum confined systems. It is also one of the simple Quantum Mechanics problems, taught in undergraduate physics courses and can be solved analytically without approximations. For example in case of metals, while explaining free electron model, the situation obeyed by particle in a box is used. It is assumed there that conduction electrons are free of the influence of local electric field of atomic origin; however, they are kept inside by the strong forces. Thus, potential is assumed constant inside the material and very large at the surface of metals and holding the electrons inside. Also in explaining Kronig Penny Model which is an idealized one dimensional model of a crystal and exhibits many features of the electronic structure of real crystals, having potential energy of an electron in an infinite sequence of periodically spaced square wells, this concept is used.

The assessment tool on theme **"particle in a box"** involved eleven questions and was administered to UG, PG students and teachers. Figure1 gives the response on the tool by UG, PG students and teachers.

Q1 was based on the fact that, zero energy leads to undefined wave function. 24% of PG students, 14% of teachers and 32% of UG students gave the correct answer in the pre-test. The score of UG students came down to 3% in the post test. Q2 was to compare the ground state energies of hydrogen and helium particles using their masses and to see how energy changes with mass. The percentage of correct answers was 56% for both PG students and teachers, whereas, for UG students percentage was 31% in the pre test which reduced to 21% in the post test. In Q3 students were supposed to differentiate between the dependence of energy on one (n) quantum number, two quantum numbers ($n_{x,}$ n_y) and three quantum numbers ($n_{x,}$ $n_{y,}$ n_z), to check manifestation of degenerate energy levels. Both PG students as well as teachers scored very less in it 36% and 18% respectively. UG students scored 17% in pre test which was increased to 23% in post test. In Q4 students were asked to compare three systems; proton, electron and a billiard ball for lowest energy. In this question, teachers scored 12% less than both UG (23% in pre test and 27% in post test) and PG students (28%). In Q5 students were supposed to appreciate the fact that for a particle in a box, negative value of n in k= nð/L makes “x negative and n=0 makes wave function zero and hence, not possible. Both UG students and teachers scored very less (4% and 6% respectively) than PG students 32%. However, in post test UG students scored 38%. In Q6 solution of Schrodinger equation for a particle in a box in an interval (0, a) was asked. Again, the score of teachers (8%) was less than both UG (14% in pre test and 22% in post test) and PG (16%) students. Q7 to Q11 were graphical questions. In general it was found that students as well as teachers found these graphical questions difficult and scored quite less. Q7 dealt with solving time independent Schrodinger equation for a particle in a square well of width “a”. Here teachers scored 72% but scores of both UG (43% in pre test and 5% in post test) and PG (6%) students was very less. in Q8 solution of time independent Schrödinger equation for an infinite square well cantered at the origin was asked. All these questions Q6, Q7 and Q8 required the application of appropriate boundary conditions and then finally normalizing the wave functions.

Q.No	Concept	Alternative Conceptions/misconceptions identified in response to the questions and interviews held later to know how students arrived at their marked responses.
1.	Particle in a box	The energy of bound state and unbound state is same. Students did not have idea that, in bound state problems, energy is found to be quantized & in unbound state, where particle is not trapped, particle will travel as a travelling wave of amplitude Ψ
2.	Ground state energy of H_2& He	Ground state energy of hydrogen and helium is same. No notion that for ground state since the mass of helium is more than hydrogen therefore energy is less
3.	Degeneracy of energy level	Meaning of degeneracy was not clear
4.	Energy level of different systems	Not able to see the Relationship between energy and length of confinement
5.	Allowed boundary conditions	No idea that if n=0 is taken then Ψ and hence probability will become zero & if n is negative then uncertainty principle will give Δx negative, which is not possible.
6.	Wave function from Schrödinger equation	It should vanish at boundaries
7.	Time independent Schrodinger equation for infinite square well	Found difficulties in interpreting meaning of boundary conditions
8.	Time independent Schrodinger equation for infinite square well at origin	Shifting of coordinate system to origin does not have any effect on solution of Schrodinger equation
9.	Relationship between wave number & wave function	Found it difficult to relate wave number & wave function
10.	Probability of finding the particle	Probability amplitude is a place where possibility of finding the particle is most. At center probability is maximum
11.	Expectation value of position	Probability density & expectation value are the same

Table 2: Alternative conceptions in various concepts of Theme “Particle in a box”

After the administration of the tool, to find out why the students have ticked a particular option while attempting the question item of the inventory and also to get an idea of their thinking process interviews were also conducted. We chose 36 UG students of one of the undergraduate colleges and 25 PG students of Physics Department, Himachal Pradesh University for this purpose. Table 2 gives alternative conceptions identified in various concepts of Theme “Particle in a box” in UG and PG students.

CONCLUSIONS

Alternative conceptions originate due to various personal experiences, observations perceptions and prior knowledge which students bring with them in the class room. They are hard to change and may create conflict with knowledge presented by conventional teaching. A student may make sense of the new information in terms of his/her own alternative way of thinking about the topic. Instructional approaches that assess students understanding of the concepts and change their alternative conceptions can act as an effective tool in the classrooms. Physics Education Research based diagnostic assessment tools play an important role to improve student learning as they help to improve their conceptual knowledge. Sometimes, teachers, overestimate our students’ prior knowledge without checking the reality, and try to build new knowledge on a shaky foundation. Introductory undergraduates’ classical physics courses focus on realist perspective and explain both present and future properties of a classical system. However, such a perspective becomes problematic for introductory quantum mechanics learner and hinders the understanding of the same models applied elsewhere for example in solid state physics course. The objective of the present work was to develop and design a validated and reliable assessment tool to investigate students’ understanding of quantum mechanics concepts which may be used prior to the teaching of courses such as solid state physics.

In this paper, statistical analysis, based on the sample of 128 UG students, 25 PG students and 50 teachers was presented which indicated that both students as well as teachers had limited and superficial understanding of fundamental concepts involved in the understanding and usage of ‘particle in box’. This exploratory study brought out alternative conceptions held not only by students but by teachers as well which also reflects on the need for teacher orientation also towards correct concepts In case of UG students we found that traditional lecture based teaching methodology was not effective enough to change their conceptions. This obtained information in this theme could become the basis for developing some teaching aids and further exploration in improving the ground situation. Technology based environment like the one simulations of certain phenomenon can be used as the pedagogical vehicle to increase the content knowledge (Sharma & Ahluwalia, 2012) and to resolve a false notion about the concept.

Future plans

In future we intend to do more intensive study by modifying some of the question items of the concept inventory focusing on addressing the alternative conceptions held by the students and then administer it again to UG and PG students for further analysis.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the support of Dr. Homeyra Sadaghiani, Assistant Professor of Physics at Cal Poly Pomona (CPP) for permitting to use some of her questions on quantum mechanics in this concept inventory.

REFERENCES

Ashcroft, N.W. and Mermin, N.D. (1976). *Solid State Physics,* Holt Rinehart and Winston.

Bao, L. & Redish, E. (2002). Understanding Probabilistic Interpretation of Physical Systems: A Prerequisite to Learning Quantum Physics, *Am. J. Phys*, *70* **(**3), 210-17

Belloni, M., Christian, W., and Cox A. J. (2006). *Physlet Quantum Physics: An Interactive Introduction,* Upper Saddle River, NJ: Pearson Education, Inc.

Cataloglu, E. (2002). Ph.D. thesis, Pennsylvania State University

Hadzidaki, P., Kalkains, G., and Stavrou, D. (2000). Quantum Mechanics: A Systematic Component of the Modern Physics Paradigm. *Physics Education*, *35*, 386-392.

Hestenes, D., Wells, M., and Schwackhammer, G. (1992). Force Concept Inventory. *Phys. Teac*., *30* (3), 141-158

Kaistha, S. (2014). Development of Concept Inventories for Statistical Physics and Quantum Mechanics to Enhance Learning of Solid State Physics, Ph. D. thesis, H.P .university, India.

Kittel, C. (1985). *Introduction to Solid State Physics*, New Delhi, Wiley Eastern Limited.

Krause, S., Decker, J., Niska, L., Alford, J. and Griffin, R. (2003). Using a Material Concept Inventory to Assess Conceptual Gain in Introductory Materials Engineering Courses, *33rd* ASEE/IEEE *Frontiers in Education Conference* Boulder, CO.

Longini, R. L. (1970). *Introductory Quantum Mechanics for the Solid State*, Wiley Inter science New York.

Maloney, D., O'Kuma, Hieggelke, T.C. and Heuvelen, A. (2001). Surveying Students Conceptual Knowledge of Electricity and Magnetism. *Am. J. Phys*., *69*, (7) S12-S23

McKagan, S.B., Perkins, K. K., and Wieman, C.E. (2010). The Design and Validation of the Quantum Mechanics Conceptual Survey, *Phys. Rev. ST Physics Ed. Research 6*, 020121

Mott, M. F., and Jones, H. (1958). *The Theory of the Properties of Metals and Alloys,* Dover Publications, Inc., New York, U.S.A

Muller, R., and Wiesner, H. (2002). Teaching Quantum Mechanics on the Introductory Level, *Am. J. Phys*, *70* (3), 202-209

Nunnally, J. (1978). Psychometric Theory, McGraw-Hill: New York.

Richardson, J., Morgan, R.S., and Dantzler. J, (2003). Development of a Concept Inventory for Strength of Materials *33rd ASEE/ IEEE Frontiers in Education Conference*.

Sadaghiani, R.H. (2005). Conceptual and Mathematical Barriers to Students Learning Quantum Mechanics, Ph. D. thesis, The Ohio State University.

Sharma, S and Ahluwalia, P.K. (2012). Diagnosing Alternative Conceptions of Fermi Energy among Undergraduate Students, *European Journal of Physics, 33*, 883.

Sharma, S., Ahluwalia, P. K. (2015). Diagnosing Alternative Conceptions in the Nature of Thermodynamic Variables and Entropy Proceedings in epiSTEME-6 an International Conference held in HBSCE (TIFR), Mumbai, page 125

Sharma, S., Ahluwalia, P.K. Development and Testing of Statistical Physics Concept Survey (SPCS Versión 1.0) for Undergraduate Students: Some Preliminary Results, unpublished

Singh, C. (2007). Helping Students Learn Quantum Mechanics for Quantum Computing, *AIP Conf. Proc., 883*, 42-45.

Singh, C. (2001). Student Understanding of Quantum Mechanics, *Am. J. Phys* , 69, 885-895

Styer, D. F. (1996). Common Misconceptions Regarding Quantum Mechanics. *Am. J. of Phys*, *64*, 31-34

Thortron, R. and Sokoloff, D. (1998). Assessing Student Learning of Newton's laws: The Force and Motion Conceptual Evaluation and Evaluation of Active Learning Laboratory and Lecture Curricula. *Am. J. Phys* , *66,* (4), 338-352

Wuttiprom, S., Chitaree, R., Soankwan, C., Sharma, M., & Johnston, I. (2006). Developing the Prototype Conceptual Survey in Quantum Physics Proceedings of the National Universe Conference Sydney, *Australia*. http://prstper.aps.org/abstract/PRSTPER/v6/i2/e020121

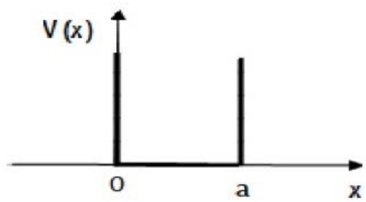
Wuttiprom, S., Chitaree, R., Soankwan, C., Sharma, M., & Johnston, I. (2008). Developing a Conceptual Survey in Fundamental Quantum Physics, *Thai Jour Phys.*, *172***,** Series 3

Zollman, D., et al. (1999). Research on Teaching and Learning of Quantum Mechanics *Papers Presented at the National Association for Research in Science Teaching*.

Zollman,D., Rebello, N.S., and Hogg, K.(2002). Quantum Mechanics for Everyone: Hands on Activities integrated with Technology, *Am. J. Phys*, *70,* 252-259

Appendix

1. A particle will not exist inside a rigid box if its energy is:



(a) zero (b) ∞ (c) < 0 (d) > 0

2. Ground state energy of Helium atom in an infinite rigid box as compared to ground state energy of hydrogen atom is:
(a) higher (b) lower (c) equal

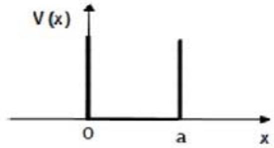
3. A particle will have degenerate energy levels in:
(a) a one dimensional box (b) a square two dimensional box (c) a cubic three dimensional box

4. The lowest energy level for a electron in a box of length 5.0×10^{-10} m, a proton or a neutron of mass 1.67×10^{-27} kg in a box of width of nucleus ($L= 1.1\times10^{-14}$m) and a billiard ball (m= 0.2 kg) bouncing back and forth between the cushions of frictionless perfectly elastic billiard table (L=1.5m) will be
(a) 1.69×10^{6}eV, 1.5 eV, 7.5×10^{-48} eV (b) 7.5×10^{-48} eV, 1.5 eV, 1.69×10^{6}eV,
(c) 1.5 eV, 1.69×10^{6}eV, 7.5×10^{-48} eV

5. For a particle in a box, we choose $k=n\pi/L$. To fit the boundary condition that $\psi = 0$ at $x = L$. The values of n are :
(a) n = 0,-1,-2,-3,…… (b) n = 1,2,3,……. (c) n = 0,1,2,3…….

6. The solution of Schrödinger equation for a particle in a box on the interval
x = [0,a] is
(a) $\psi = (\sqrt{2}/a) \sin (n\pi x/a)$ (b) $\psi = (\sqrt{2}/a) \cos (n\pi x/a)$ (c) $\psi = (\sqrt{2}/a) \tan (n\pi x/a)$

7. An electron is confined to a one-dimensional, infinitely deep potential energy well of width a depicted below.
V (x) = 0, for 0 < x < a
= +∞, for x <0, x > a



Solution of the time-independent Schrödinger equation with appropriate boundary conditions for this square well is

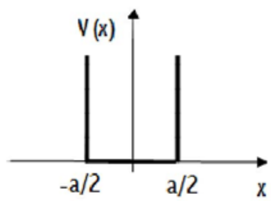
(a) $\varphi_n(x) = (\sqrt{2}/a)\ \sin\ (n\pi x/a)$; n=1,2,3…….. (b) $\varphi_n(x) = (\sqrt{2}/a)\ \cos\ (n\pi x/a)$; n=1,2,3……..

(c) $\varphi_{n(x)} = (\sqrt{2}/a)\ \tan\ (n\pi x/a)$; n=1,2,3…….

8. How does your answer change for the infinite square potential well cantered at the origin?

V (x) = 0, for — a/2 < x < a/2

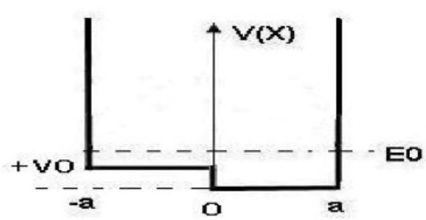
= +∞, for x >a/2



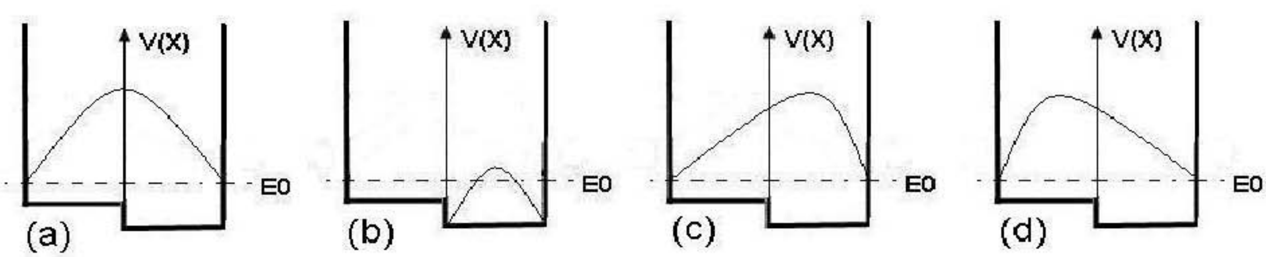
(a) $\varphi_{2n-1} = (\sqrt{2}/a)\ \sin\ (n\pi x/a)$; n=1, 2, 3……. b) $\varphi_{2n-1} = (\sqrt{2}/a)\ \cos\ (n\pi x/a)$; n=1,2,3……..

(c) $\varphi_{2n-1} = (\sqrt{2}/a)\ \tan\ (n\pi x/a)$; n=1, 2, 3……

9. The plot below shows a potential energy function V(x) versus x, corresponding to an asymmetric infinite well. The infinite well is of the width 2a, with impenetrable walls at x= a but where V(x) = + Vo for x between (-a, 0) and V(x) =0 for x between (0, +a)



Of the figures below, which is /are more most likely to be physically acceptable energy eigenstate solutions for the time-independent Schrödinger equation for this well ?

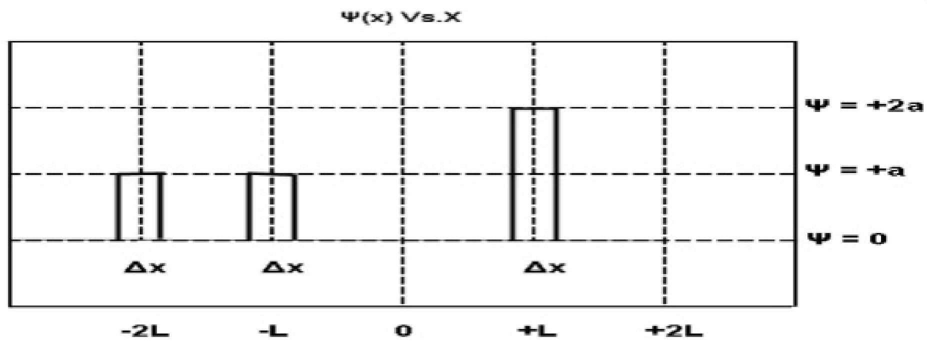


(a) b (b) a (c) d (d) c

10. Consider an infinite square well of width L with a single electron in it. If someone performs a measurement of the electrons' energy and tells you that they found the electron to have energy of n=2 eigenstate, at what positions is the electron most likely to be found?

(a) L/2 (b) L/3, 2L /3 (c) L/4, 3L/4 (d) 0, L/2, L (e) probability is same everywhere.

11. The figure below shows a plot of a wave function $\psi(x)$ versus x, over the range of (-2L, +2L). The wave function vanishes for all other values of x. What is the expectation value of x?



(a) < x > = 4L/6 (b) < x > = - L (c) < x > =0 (d) < x > = L/6 (e) < x > = - L/4

INDIAN STUDENTS' UNDERSTANDING OF PARTICULATE NATURE OF MATTER

Puneeta Malhotra
C.I.E., University of Delhi
puneeta_krm@yahoo.co.in

Understanding of Particulate Nature of Matter is the foundation for learning chemistry. Appreciating this fact, the topic finds space in the school science curriculum across the globe. This topic is abstract so students find it difficult to understand. This paper is an attempt to identify common alternative conceptions related to the particulate nature of matter amongst students in India.

INTRODUCTION

"If, in some cataclysm, all of the scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis that *all things are made of atoms — little particles that move around in perpetual motion, attracting each other when they are a little distance apart but repelling upon being squeezed into one another.* In that one sentence, you will see, there is an enormous amount of information about the world if just a little imagination and thinking are applied."

The above statement by Richard Feynman describes the importance of atomic theory in science. Atomic theory is the foundation of science, thus the foundation of science education as well. For comprehending science whether it is chemical reactions, nuclear behavior, chemical bonding, shapes of molecules; understanding the atom and its structure is indispensable. It is therefore not surprising that the atomic theory is an essential part of the science curriculum across the globe. The need for learners to appreciate the particulate nature of matter drives the inclusion of the topic in the school science curriculum. Not surprising, school curriculum across the globe has given due credit to particulate theory. The theory is introduced to students in the middle school who are in the age group of 11-13 years.

Atomic Theory is a difficult concept with abundant alternative conceptions in the mind of the learner. Alternative conceptions are frequently observed in the student's understanding of atoms. (Nakiboglu, 2003; Park and Light, 2009). Lack of understanding of the theory can be attributed to the abstract nature of the topic. The cognitive readiness of the students is essential to understand abstract topics like atom and the structure of an atom. Therefore until a child reaches the formal operational stage, the introduction of this topic will be a futile exercise. The cognitive preparedness of the child is foremost for curriculum development, it should be cognitively valid (National Curriculum Framework, 2005) [NCF]. Keeping the developmental phase of learners in mind, the National Research Council USA (1996) recommended the introduction of the topic in Grades 9 -12, which is the same in India as well, barring a few exceptions. Following the guidelines of NCF 2005, the Atomic theory is introduced in grade 9 in the CBSE curriculum. The child has attained the age of 14 years when he enters this grade. According to Piaget, this child is now capable of abstract reasoning.

Another problem inherent with microscopic particles is the inability of the students to 'see' the particles leading to association and analogy with a macroscopic system at least initially to understand the abstract topic. The structure of an atom is associated with the 'watermelon and its seeds' as in the case of the Thomson model or 'solar system' in the case of the Rutherford model. The initial engagement with these analogies is so strong that the student falls back to these models time and again.

To add to the problem is the association with the term 'model'. Models used as intellectual tools to aid scientific inquiry are seen as students as a replica of reality. (Grosslight, Unger, Jay, & Smith, 1991, p. 799). Students assume scientists have 'seen' the atom using some sort of special instrument like a special microscope. The colorful 'images of atoms' that are readily available have further strengthened this belief of students. The computer-generated models of atoms appear in different publications of scanning tunneling microscope as 'images of atoms'. These images mislead people. These are assumed to be 'atom' as seen through the scanning tunneling microscope (Harrison & Treagust, 1996). Therefore, the student's belief in being able to see an atom is strengthened.

Molecules are too small to be seen, but these can be seen using some "magnifying lenses". This belief is deep, even after repeated instruction, students feel even if faintly, an atom can be seen. Even after the repeated emphasis on the fact that even with the most powerful microscopes atom is not visible, this alternative conception stands. (Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993)

The researcher came across this strong conviction of scientists have seen an atom while an informal conversation with her students. "I have not seen an atom, but scientists have. I saw the images on the INTERNET" a student said. "Like the model of an internal combustion engine or like the model of kidneys and heart, is the model of an atom" she added. The response can be related to the study by Horton (2007). In the study on alternative conceptions in chemistry, he found that none of the students under study understood that models were not depiction of reality. There was a great difficulty encountered by the students in understanding something they were not able to see.

The content and diagrams that appear in the textbooks add on to the woes. Joshi & Sudhir (2017) question the treatment of this important topic in a superficial manner. The diagrams, they write, are misleading. Expansion of solids on heating is greatly exaggerated and decrease in density of liquid on changing to gas is under represented. This leads to alternative conceptions related to densities of the three states of matter. These problems, related to abstractness of the topic, are responsible of mushrooming alternative conceptions amongst students and not surprisingly also amongst pre service and in service teachers (Kikas, 2004; Nakiboglu, 2003; Haidar, 1997).

Particulate Nature of Matter

Introducing atom, molecule and ion to a child who does not comprehend particulate nature of matter is a futile task. Distinction between the macroscopic properties of matter and the properties of particles is not clear to majority of students. The properties of bulk of matter are transferred to individual particles. The commonly held alternative conceptions in this topic are:

Matter is Continuous

Doran (1972) listed alternative conceptions that commonly occur related to particulate nature of matter. The most common one is considering matter is continuous. The idea of existence of empty space is not internalized by students. They believe there is no space between particles of matter. There is 'nothing' between the particles is not accepted by students. The particles are either in contact (Nakhleh, 1992) or float in some medium (Andersson, 1990; Harrison, 2001) or particles have something like air in between them, (Lee et al., 1993) is a strongly held notion.

According to Lee et al. (1993), this strongly held notion includes 'various kinds of 'stuff [or air] between molecules' (p. 257). Andersson (1990) and Harrison (2001) both found textbooks containing diagrams like Figure 1 where the line across the top tells students that water molecules are floating in some other 'stuff! The students interpret the line on the top in diagrams like figure 1 as water molecules are floating in some other 'stuff!'. Study by Griffiths & Preston (1992) echoes similar results.

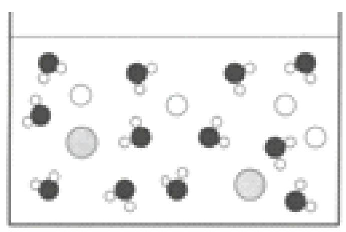


Figure 1: A model of a liquid in a container with surface line implying that the particles are suspended in another substance

Particles of Matter Do Not Move

Many students believe that particles of solid are static. The particles are tightly held and are rigid so no motion is possible in solids. Doran (1972) and Lee et al. (1993) identified students are unable to value the notion of movement at particulate level. The movement of particles in gases is seemingly easily appreciated by students. Though, the belief that when some gas is sucked out of a container, the gas does not fill the container, points at an alternative vision about gas particle. (Nussbaum & Novick, 1982).

Spacing between Particles

Overestimation of distance between particles of liquids is frequently encountered alternative conception. Students however view particles of liquid at a distance that is somewhere intermediate of solid and gas particles. Scientifically, the spacing between solid-solid, liquid- liquid and gas-gas particles is about 1: 1: 10 (Andersson, 1990; de Vos & Verdonk, 1996). Commonly held student view about particles is that: solid particles are in contact, liquid particles about a particles away and gas particles three to four particles away(Harrison, 2001).

The perception of inter-particle distance between different states of matter is directly derived from the textbook representations. Figure 2, shows the depiction of space between particles of solid, liquid and gas from the NCERT Science textbook (class IX). The diagram is misleading. According to this diagrammatic representation, the density of solid would be at least twice that of liquid and that of gas four times the liquid state. This is not true for any known substance. (Joshi & Sudhir, 2017)

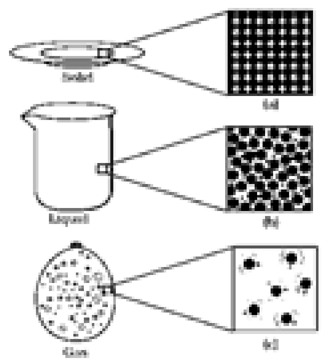


Figure 2: Depiction of distance between particles in solid, liquid and gas.

Properties of Substance are Properties of Particles

Macroscopic properties like colour, malleability, electrical conductivity are considered to be properties exhibited by each individual atom. Ben-Zvi, Eylon, and Silberstein (1986) in their study found nearly 85% students of grade 10 from different schools in Israel thought properties of matter are manifested by an atom. Only 14.9% of the students out of a sample of 288 stated that an atom cannot be isolated or the properties like colour, malleability, conductivity are properties of cluster of atoms.

Atom appears in multicolored images in modern textbooks. These add on to students conceptions of colour of atom. The difference in colour of reactant and products can be used to debate on colour of atom (Albanese & Vicentini, 1997).

Joshi & Sudhir (2017) also reported teachers believe an atom of copper is a better conductor of heat and electricity than an atom of mercury. Also, measurement of temperature of an atom is possible, provided we have the correct instrument. Therefore, teachers attribute bulk properties of matter to properties of the constituent particles. The students are thus likely to develop these alternative conceptions.

A study from Israel conducted by Ben-Zvi et al., (1986), too voices concern about students understanding of atomic theory. Responses of nearly 67% of the students from a sample of 300 high school students, reflected that the 'continuous model' of matter was deep rooted. They knew the particulate model but were not able to internalize the concept. For them, atom has same properties as the substance and atoms of solid and gas are different.

The views about particulate nature of matter of 54 prospective elementary teachers of Indiana University, Kokomo, Indiana were studied by Gabel, Samuel and Hunn (1987). The examination of students drawings depicting what happens to particles after physical and chemical change, revealed distorted understanding of particulate nature of matter. The diagrams show change in size of constituent particles when the phase changes and gaseous particles in an ordered arrangement rather than random arrangement. After decomposition reaction, the molecules were still intact as if in a physical change. The misconceptions (author uses this term) related to change of size, no change in inter-particle distance and arrangement as well as poor understanding of physical and chemical change is prevalent.

Study of perceptions about particulate nature of matter in the United States also hints at the struggle of students in comprehending the topic. A sample of 87 high school and middle school students, of schools ranked for their academic performance in US was assessed for their conceptual understanding of particulate nature of matter. Aydeniz & Kotowski (2012) reported the following misconceptions (term used by authors) held by significant number of students: (i) During phase change, chemical composition of the substance changes. The author cites example of students stating boiling of water involves breaking of bonds between hydrogen and oxygen. They visualize phase change as a chemical change rather than a physical change. (ii) Nearly 70% students think a gas formed during change of state (boiling or sublimation) weighs less than the liquid or solid. The "law of conservation of mass" is not internalized by the students. The analysis reported possible reason for such a misconception was students' belief that the size of molecules changes during phase change.

Students (sample of 20) at the Education Department of the University of Cyprus who opted for a compulsory science course had conflicting views regarding particles of matter. Valanides (2000) cited lack in understanding of empty space between particles, constant motion of particles in all states of matter, particles do not expand or contract during phase change and particles do not melt during the process of melting.

Looking at studies from Africa, similar problem in understanding of particulate matter have been reported. A study of 30 high school pre service teachers, showed lack of understanding of effect of phase change on size of particles. The study was conducted by Banda, Mumba, Chabalengula and Mbewe (2011) which reported 89.7% of the sample associated melting and freezing result in change in size of the particles. Similarly, more than 75% associated vaporization and condensation involves change in size of particles. However, the understanding of distance between the particles, speed and number of particles was in accordance to scientific understanding for nearly 70% of the sample.

The only study from India, which the researcher came across was by Chakraborty & Mondal (2012). The sample was 189 students of grade 9 of four schools situated in Murshidabad district of West Bengal, India. The students were reported to have difficulty in the understanding of mass number, atomic nucleus and shells. No other study was available from India. The researcher decided to conduct a study to find out the alternative conceptions related to particulate nature of matter held by students of grade XI in India.

METHODOLOGY

The study was conducted in two private schools in National Capital Region. The students, who chose science stream in grade XI, were chosen as sample. These students have studied particulate nature of matter in detail in grade IX. The sample of 60 students was selected on basis of section allocation done by school.

A questionnaire was prepared to test the understanding of particulate nature of matter. The questionnaire consisted of 15 multiple choice questions (MCQ) and 4 open ended questions. Out of the 15 MCQ 11 were taken from Particulate Nature of Matter Assessment (ParNoMA) Yezierski & Birk (2006) and rest from Merritt (2010).The open ended questions were taken from studies by Merritt(2010) and Ben-Zvi et al. (1986) and Kokkotas, Vlachos and Koulaidis (1998)**.** 10 students of class XI were part of pilot stage. Responses of students were studied. Open ended interviews were conducted for all 10 students to understand their responses. Questions were changed or re-framed based on the students' responses.

Questions which intended to assess clarity of inter particle distance in different states of matter were reframed. During interviews it was realized that the problem area is inter-particle distance in liquid state, so questions were re-framed. The changed question tested understanding of particles in liquid state. In another question, student's seemed to understand evaporation as breaking of water molecules away from other water molecules, but clarity of what this 'breaking away' meant was missing. Interviews showed, it was majorly thought as breaking of covalent bond, so this question was re-framed. Diagram showing hydrogen bonds and covalent bonds was given asking about which bond(s) are broken during evaporation.

Question on what lies between particles of matter, many students answered 'nothing', which was the correct option. Interview revealed that students thought amongst the options provided, only nothing fits, which actually means something. Like when we see an empty glass, it has nothing that we can see but it actually has air.

All open ended questions were re-framed after getting an initial feeler of possible gaps in Understanding of Particulate Nature of Matter.

Following the pilot stage, questionnaire was sent to experts for their comments. The questionnaire was vetted by experts Dr Uma Sudhir and Dr Arvind Sardana from Eklavya. The questionnaire was then administered to the sample.

Data Analysis

The data was analysed to draw out the alternative conceptions if any held by the students. 1 mark was allotted for each correct answer and 0 for incorrect answer in MCQ. The open ended question correct answer was awarded 1 mark and correct reason 1 mark. To understand the answers better interviews of students were also conducted.

On analyzing the data, it was found that 50% students assumed solids are immobile. Students associate mobility with particles of liquids and gases as these two states are fluids. Solids are seen as fixed, so the students face difficulty in understanding motion at particulate level.

Nearly 50% students assume distance between particles of liquids is intermediate of solids and gases. The reason that came out on the basis of interviews was the diagrams given in textbooks show space between liquid particles more than solid and less than gas particles.

Particles change in size and melt or boil when state change occurs, is assumed by nearly 45% of the students. Daily experience of comparative densities of solid, liquid and gas is responsible for students' assumption that particles of gas are lighter than liquid while that of solid heavier. On probing further, it was found students do mention that the inter-particle distance changes on state change but macroscopic observation is a barrier to understanding what happens at particle level. Similarly students' understanding that particle of a shiny substance shines, of a grey substance is grey and of a conductor is a good conductor shows bulk properties are properties of the particles too. This was observed in 70% of the responses.

Another alternative conception which was found in 60% of the students was matter is continuous. There is something, maybe air between particles of matter. As when we say the glass has nothing, it means glass has air, said one of the students during the interview.

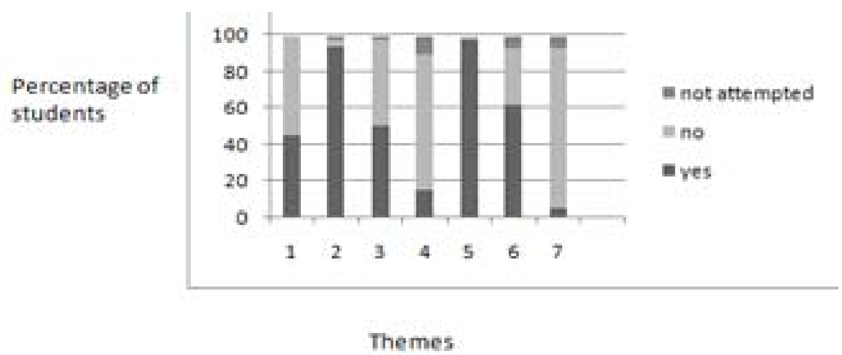


Figure 3: Percentage responses of students on themes 1 to 7 (1: decomposition occurs on boiling, 2:atom conducts electricity 3: atom has colour 4: size of particle changes on state change, 5: overestimation of distance between liquid particles, 6: solid particles are immobile and 7:particles melt.)

CONCLUSION AND IMPLICATIONS

Nearly 50% students who have chosen science stream in class XI are found to have alternative conceptions related to particulate nature of matter. The students have studied the atomic theory in detail in class IX. Also in class X they have studied chemical reactions, periodic classification and types of bonds. The data analysis is a striking revelation about understanding of basic concepts in chemistry. These alternative conceptions will impede their understanding of chemistry at senior school level. Students who associate breaking of covalent bonds with state change actually have little understanding of physical and chemical changes. The idea that size and weight change with change of state will affect their understanding of periodic classification. The overestimation of inter-particle space in liquids is also responsible for the understanding that liquids are compressible to some extent. Inability to appreciate compressibility of gases is due to under estimation of distance between its particles. Poor understanding of evaporation and boiling can be associated with the alternative conception that temperature of a substance is same as temperature of each of its particles and not dependent on its average kinetic energy.

More than 95% students assume atom to have same colour as the substance. From this study, for example, it came out that students assume sulfur atom to be yellow as sulfur is yellow in colour. Making note of alternative conceptions (as represented in figure 2) teachers can plan their lessons in a manner that these conceptions are hit upon. While teaching atomic theory, a teacher can question students about colour of carbon atom. They may reply black as graphite is black. Initiate a debate, why black? Will it be a conductor? Why do you think carbon atom will conduct or not conduct electricity? Let them compare graphite atom to atom of diamond, which is also carbon, and now explain what will be colour of atom, or conductivity. Create a confusing situation and let students resolve the confusion and arrive at scientifically correct conception. Teacher can also weave in historical development in understanding of atom. Starting with initial thoughts that atoms of iron have hooks and that of cheese are cheesy and correlate it to student's idea of atom of carbon being black.

Chemistry teachers often face difficulties in teaching topics like chemical bonding, evaporation, boiling, periodicity of properties of elements to name a few. The cause of these can be traced back to poor understanding of particulate nature of matter. Therefore, it is essential for teachers to be aware of alternative conceptions of students and to find out means to reduce these. Use of historical narratives, computer simulations and philosophical debates are a few methods which can be used to reduce these alternative conceptions.

ACKNOWLEDGEMENTS

I would like to thank Prof Sadhna Saxena for her guidance and support in this research.

REFERENCES

Albanese, A., & Vicentini, M. (1997). Why do we believe that an atom is colorless? Reflections about the teaching of the particle model. *Science & Education, 6*(3), 251-261.

Andersson, B. (1990). Pupils, conceptions of matter and its transformation (age 12-16). *Studies in Science Education, 18,* 53-85.

Aydeniz, M., & Kotowski, E. L. (2012). What Do Middle and High School Students Know About the Particulate Nature of Matter After Instruction? *Implications for Practice. School Science and Mathematics, 112*(2), 59–65.doi:10.1111/j.1949-8594.2011.00120.x

Banda, A., Mumba, F., Chabalengula, V. M., & Mbewe, S. (2011, December). Teachers' understanding of the particulate nature of matter: The case of Zambian pre-service science teachers. *In Asia-Pacific Forum on Science Learning and Teaching* , *12*(2), 1-16. The Education University of Hong Kong, Department of Science and Environmental Studies.

Ben-Zvi, R., Eylon, B. S., & Silberstein, J. (1986). Is an atom of copper malleable?. *Journal of chemical education, 63*(1), 64.

Chakraborty, A., & Mondal, B. C. (2012). Misconceptions in Chemistry at IX[th] Grade and Their Remedial Measures.

Doran, R. L. (1972). Misconceptions of Selected Science Concepts Held by Elementary School Students. *Journal of Research in Science Teaching, 9*, 127-137.doi:10.1002/tea.3660090204

Gabel, D.L. , Samuel, K.V. , & Hunn, D. (1987). Understanding the Particulate Nature of Matter. *Journal of Chemical Education, 64*(8), 695.

Griffiths, A.K., & Preston, K.R. (1992). Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules. *Journal of Research in Science Education*, *29*(6), 611–628.

Grosslight, L., Unger, C., Jay, E. and Smith, C.L. (1991), Understanding models and their use in science: Conceptions of middle and high school students and experts. Journal of Research in Science Teaching, 28: 799-822. doi:10.1002/tea.3660280907

Haidar, A. H. (1997). Prospective chemistry teachers' conceptions of the conservation of matter and related concepts. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 34*(2), 181-197.

Harrison A.G., (2001), Textbooks for outcomes science: a Review, *The Queensland Science Teacher, 27*, 20-22.

Harrison A.G. and Treagust D.F., (1996), Secondary students mental models of atoms and molecules: implications for teaching chemistry, *Science Education, 80*, 509-534.

Horton,C. (2007). Student misconceptions in chemistry. *California Journal of Science Education, 7*(2), 18-38.

Joshi S & Sudhir U (2017). *The Story of Atomic Theory of Matter*. Eklavya . Bhopal, MP, India

Kikas, E. (2004). Teachers' conceptions and misconceptions concerning three natural phenomena. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 41*(5), 432-448.

Kokkotas, P., Vlachos, I., & Koulaidis, V. (1998). Teaching the topic of the particulate nature of matter in prospective teachers' training courses. *International Journal of Science Education, 20*(3), 291-303.

Lee, O., Eichinger, D.C., Anderson, C.W., Berkheimer, G.D., & Blakeslee, T.D.(1993). Changing middle school students' conceptions of matter and molecules.

Merritt, J. D. (2010). Tracking students' understanding of the particle nature of matter (Doctoral dissertation, University of Michigan).

Nakhleh M.B., (1992), Why some students don't learn chemistry: chemical misconceptions, *Journal of Chemical Education, 69*, 191-196.

Nakiboglu, C. (2003). Instructional misconceptions of Turkish prospective chemistry teachers about atomic orbitals and hybridization. *Chemistry Education Research and Practice, 4(2),* 171-188.

Nussbaum J., & Novick, S. (1982). Alternative frameworks, conceptual conflict and accommodation: Toward a principled teaching strategy. *Instructional Science, 11,* 183-200.

Park, E.J. & Light, G. (2009). Identifying Atomic Structure as a Threshold Concept. Student mental models and troublesomeness. *International Journal of Science Education, 31(2)* , 233-258.

Valanides, N. (2000). Primary Student Teachers' Understanding of the Particulate Nature of Matter and its Transformations During Dissolving. *Chemistry Education Research and Practice, 1(2),*249-262.

Yezierski, E. J., & Birk, J. P. (2006). Particulate nature of matter assessment.(ParNoMA) [Supplemental material]. *Journal of Chemical Education, 83*(6).

BEYOND CONTENT AND SKILLS: MISALIGNED EPISTEMOLOGICAL BELIEFS FOR SCIENCE AND BIOLOGY LEARNING

Kyriaki Chatzikyriakidou[1]* and Melissa McCartney[1,2]
STEM Transformation Institute[1] and Department of Biological Sciences[2],
Florida International University, Miami, FL, 33199
kchatzik@fiu.edu

This study explores college biology students' epistemological beliefs about science and biology learning using a previously developed tool; the MBEX (Maryland Biology Expectations) survey. The survey was administered in an introductory biology course, at the beginning (pre-) and end of the semester (post-) and differences in students' epistemological beliefs were calculated between post-pre. None of the changes was found to be significant, with a majority of students (61% of n=161) holding the same mismatch of epistemologies throughout the academic semester. Although students' science epistemologies are favourable, they are not aligned with their epistemologies about learning biology when it comes to an introductory biology course. Students seem to bear a group of unfavourable epistemological beliefs relevant to their classroom learning. Development of instructional approaches that could foster the development of student science epistemologies and align them with those about biology learning is necessary in order to advance college biology education.

INTRODUCTION

Although college biology students usually excel in knowing facts about different biological principles, it has been well-documented that they lack critical thinking, experimental hypothesis development, and data interpretation abilities (Barnett & Francis, 2012; Butler et al., 2012; Flores, Matkin, Burbach, Quinn, & Harding, 2012). In addition, the learning goals and assessment items of introductory biology courses have been found to focus more on memorization of facts rather than higher-order cognitive skills (Momsen, Long, Wyse, & Eber-May, 2010).

Several publications have discussed the need to create learning environments where students are supported towards the development of higher-order cognitive skills (American Association for the Advancement of Science, 2011) [AAAS]. Content and procedural knowledge is important for the development of students' scientific skills, however epistemological beliefs may play as important of a role as well (National Research Council, 2012) [NRC].

Epistemological beliefs are an individual's beliefs about the nature of knowledge and nature of knowing (Hofer, 2004; Schommer-Aikins, 2004; Hofer & Pintrich, 1997). Epistemological resources are "smaller in size" than beliefs, providing a finer unit of analysis for research studies on students' epistemologies. An epistemological resource is an individuals' perception of the source of their own knowledge, in other words, the understanding of “how do I know what I know,” which is necessary to develop their personal epistemology (Hammer & Elby, 2002; Hofer, 2006). Building on diSessa’s knowledge in pieces (diSessa, 1993), epistemological resources can be seen as units of thought, which are context-dependent. This means that when a student’s epistemological resources are activated in the right context, they can be productive reasoning tools that students use to understand a phenomenon (Hammer, 2000). In other words, epistemological resources can shape a student’s beliefs for scientific knowledge and biology learning. As such, the MBEX (Maryland Biology Expectations Survey) was designed to help educators unravel biology students’ epistemologies about science and biology learning and it has been used in large-enrollment introductory courses (Hall, 2013).

There is evidence that the development of epistemology is affected by the characteristics of the learning environment where a learner is situated (Hofer, 2001). However, literature reporting biology students’ epistemological beliefs for science and biology learning is scarce. The aim of this study was to investigate the question “What are the introductory biology students’ epistemological beliefs at the beginning and end of the semester?” The study was completed in a fast-paced introductory biology class, without any particular class implementation focusing on epistemology. The aim of this study was to measure biology students’ beliefs about science and biology learning in class, in order to invite conversations regarding the epistemic climate of large-enrollment introductory biology courses.

METHODS

Participants and course information

Participants of this study were students enrolled in an introductory biology course at a large public R1 institution during the spring semester of 2017. A total of 83% of the student population (n=392) were freshmen and the course is required for biology majors. Some non-majors were also enrolled because they needed to fulfil a requirement for an introductory biology course. The course has three main parts: 3 lectures of 50min. per week, 1 weekly discussion of 75min., and 3h long weekly laboratory sessions.

Maryland Biology Expectations (MBEX) survey

To examine the changes in student’s expectations about scientific knowledge and biology learning, the MBEX survey (Hall, 2013) was administered to students at the beginning (pre-) and end (post-) of the semester. The MBEX survey is composed of a total of 32 questions: 24 five-point Likert scale from strongly disagree (1) to strongly agree (5), 3 open-ended questions, and 4 multiple-choice questions. MBEX questions measure student beliefs along four different dimensions/clusters: I) Facts vs. Principles, II) Independence vs. Authority, III) Interdisciplinary Perspectives vs. Silo Maintenance, and IV) Connected vs. Isolated. Clusters I and II included 5 overlapping questions, according to the original survey’s structure. Only multiple-choice questions were used in this study.

Data Analysis

Only responses of students who had consented (during the pre-survey) to participate in this study were used for data analysis. Any students with incomplete survey profiles (with >50% missing responses) were removed from the dataset as those who did not complete the post-survey. The final paired dataset was composed of 161 students who had completed both pre- and post-surveys. The number of favourable, neutral, and unfavorable responses were counted for each question and each survey. Favourable responses can be seen either as experts' beliefs or, alternatively, beliefs that the instructors would like their students to have. When a favorable response is associated with the first two Likert choices, then the last two will be associated with the unfavorable response and vice versa. Shifts in student beliefs were calculated by subtracting the pre-scores (favourable, neutral, unfavourable) from the post-scores (favourable, neutral, unfavourable) for each question and for each student. In previous research, it has been found that a shift of 5% in a particular cluster is considered statistically significant (Hall, 2013).

RESULTS

Overall, beliefs of students tended to favourable ones in all four clusters of MBEX survey during an academic semester (Table 1). On average, a majority (pre%, post%) of students believed that scientific knowledge should be independently built (Cluster II, 73%, 70%), interdisciplinary (Cluster III – 58%, 56%), based on principles (Cluster I – 72%, 72%), and connected (Cluster IV – 62%, 58%). However, when a further break down of each MBEX cluster's statements were made, it was seen that these beliefs are opposite from those students have about learning biology, where facts seem to matter more than concepts, knowledge coming from the instructor seems most important, and connections with the real-world or other disciplines can not be easily made. A brief description is given for each MBEX cluster:

Beliefs about Facts vs. Concepts - Cluster I (pre%, post%)

Almost half 53%, 53% (pre%, post%) of the total student population disagreed that "Learning biology is mainly a matter of memorizing the various facts presented", however only 25%, 37% of the students agreed with the statement "I am more interested in general biological principles than the specific facts that demonstrate those principles." Similar results for this question were found by Hall (2013), where the majority of students disagreed with this statement in all the various courses studied. On the other hand, 89%, 88% of students agreed with the belief that learning biology concepts for a test and organizing information should not be done verbatim, but in a self-constructed way, and 71%, 71% of them agreed that their exam performance in biology courses should reflect how well they "apply course material to situations not discussed in class."

Beliefs about Independence vs. Authority – Cluster II (pre%, post%)

73%, 70% of students seemed to prefer independent learning instead of relying on knowledge coming from an authority. However, 40%, 41% of the students agreed that exams should be made of "A large collection of short-answer or multiple-choice questions, each of which covers one specific fact or concept," in contrast to the favourable response "A small number of longer questions and problems, each of which covers several facts and concepts." Regarding organization of biology textbooks, 89%, 88% of students agreed that "A good biology textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each chapter as separate because they're not really separate." In addition, 52%, 39% of students disagreed with the statement "If biology professors gave really clear lectures, then most good students could learn the material without having to spend a lot of time thinking outside of class." This belief shows that learning is associated with studying outside class and that students expect to spend time independently (without an instructor) to complement their classroom experiences.

	Pre-survey (%)			Post-survey (%)			Differences (%)			
Q #	Fav.	Neut.	Unfav.	Fav.	Neut.	Unfav.	Fav.	Neut.	Unfav.	
1	*53	26	21	53	20	27	0	-6	+6	Cluster I
3	86	12	2	84	12	4	-2	0	+2	
6	**25**	**30**	**44**	37	33	30	+12	+3	-14	
16	86	7	6	83	13	4	-3	+6	-2	
20	71	n/a	29	71	n/a	29	0	n/a	0	
21	92	n/a	8	92	n/a	8	0	n/a	0	
22	89	n/a	11	88	n/a	12	-1	n/a	+1	
23	60	n/a	40	59	n/a	41	-1	n/a	+1	
24	89	n/a	11	84	n/a	16	-5	n/a	+5	
Av.	**72**	**19**	**19**	**72**	**19**	**19**	**0**	**0**	**0**	
1	**53**	26	21	53	20	27	0	-6	+6	Cluster II
4	65	26	9	63	16	21	-2	-10	+12	
5	**52**	**27**	21	39	27	34	-13	0	+13	
17	92	6	2	80	9	11	-12	+3	+9	
20	71	n/a	29	71	n/a	29	0	n/a	0	
21	92	n/a	8	92	n/a	8	0	n/a	0	
22	89	n/a	11	88	n/a	12	-1	n/a	+1	
23	60	n/a	**40**	59	n/a	41	-1	n/a	+1	
Av.	**73**	**21**	**19**	**70**	**18**	**23**	**-3**	**-3**	**+4**	
2	46	37	17	42	34	24	-4	-3	+7	Cluster III
8	45	29	26	40	34	27	-5	+5	+1	
12	40	34	**27**	38	38	24	-2	+4	-3	
14	**35**	**40**	25	42	30	28	+7	-10	+3	
18	65	31	4	60	31	9	-5	0	+5	
19	96	4	1	91	6	2	-5	+2	+1	
Av.	**58**	**30**	**15**	**56**	**30**	**17**	**-2**	**0**	**+2**	
7	89	4	6	80	12	9	+9	+8	+3	Cluster IV
10	84	15	1	72	19	9	-12	+4	+8	
11	67	25	8	66	20	14	-1	-5	+6	
13	**22**	**29**	**49**	23	25	52	+1	-4	+3	
15	84	15	1	80	13	7	-4	-2	+6	
Av.	**62**	**20**	**17**	**58**	**19**	**22**	**-4**	**-1**	**+5**	

Table 1: Differences in the percentages of favorable, neutral and unfavorable responses per each question of each cluster of the MBEX survey.

*No decimal places are shown, numbers are rounded up.
Highlighting shows the lowest and highest percentages in each cluster in the pre-survey

Beliefs about Interdisciplinary perspectives vs. Silo maintenance Cluster III (pre%, post%). Freshmen in this university seemed to recognize the value of learning chemistry along with biology (96-91% agreed for chemistry), but not so for physics (35-42% agreed) and mathematics (46-42% agreed). A high number of neutral responses (ranging between 29%-40%) were seen in this cluster, which may indicate indecisiveness of students over agreeing or disagreeing with a statement about interdisciplinary knowledge coming from a lack of personal interest or expectations. These results are probably not surprising for the introductory biology course population of this study, since there was no overlap between the course's syllabus and physics or mathematics courses. Hall's results on high unfavourable scores (33%) (and 27% neutral), even in reformed interdisciplinary biology courses, may show that a particular learning environment may not be enough to shift student beliefs (Hall, 2013).

Beliefs about Connected vs. Isolated Knowledge – Cluster IV (pre%, post%)
A majority of students (62%, 58%) agreed that knowledge learned in this class can be applied to other situations. Similar findings have been reported on the real-world connection part of the CLASS-Bio survey (Colorado Learning Attitudes about Science Survey), where 65% of majors and 53% of non-majors expressed similar beliefs in the pre-survey (Mollohan, 2015). However, about half of the students (49%, 52%) agreed with the statement "Biology classes should be designed to help students master the factual material for doing well on the MCATs, GREs, and other professional exams." This expectation probably results from the ambition of many introductory biology students to follow professional careers and their high interest in these required performance tests. Along with the agreement with the statement "Biology class should just present all the different facts. Trying to present the unifying theories doesn't really help us understand anything" (86%, 84% - from Cluster I), it is interesting to note that these statements imply fact-based learning having taken place in an introductory biology course.

DISCUSSION

On a per student analysis, this study found that out of total 161 students (paired data), 82 students shifted negatively, 16 did not change their beliefs, and (65) shifted positively (ranging from 1 to 10 out of 24 total responses), using the MBEX survey. Considering each cluster's averages of favourable and unfavourable responses (Table 1), no significant (>5%) shifts were found, however students shifted their beliefs either favourably or unfavourably for specific items of each cluster. It was also noticed that the variety of favourable-unfavourable scores per student was greater in the post-survey, indicating that their beliefs shifted throughout a semester of introductory biology. Hall has previously reported shifts ranging from 0% to 2% for Organismal Biology course, which is similar to the introductory biology course described in this study (Hall, 2013). On the other hand, comparing these findings with the conceptual connections/memorization part of CLASS survey, it was found that the epistemic beliefs of introductory biology students who were majors had largely shifted towards novice-like beliefs (-39.7), however positive shifts (+1.8) were seen for the non-majors. The authors are unsure about the reasons for these shifts (Mollohan, 2015).

What students are invested in learning is affected by what they believe about science. In this study, when students were asked whether "Knowledge in biology consists of many unrelated facts," (#3, Table 1) 86%, 84% (pre%, post %) of them disagreed with this statement, however only 53% disagreed with the statement "Learning biology is mainly a matter of memorizing the various facts presented" (#1, Table 1). The difference between these two questions is that the first one asks about the nature of (scientific) knowledge in general, whereas the second one asks about the environment of learning biology, which students probably relate to their classroom experiences. Memorization of facts may appear more practical or applicable in a fast-pace introductory biology course, even though students recognize that the science of biology is perceived as a coherent network of biological principles. When we informally asked students about how they studied for the final exams, one statement was: "I found I didn't have enough time to make all the connections I wanted to be able to do well in this course but I definitely think it helps."

In pre- and post- surveys respectively, 40% and 41% of students agreed that "a large collection of short-answer or multiple-choice questions, each of which covers one specific fact or concept" (#23, Table 1) is the best way to measure how well students understand the material, positioning them against conceptual understanding. Students seem to understand their role in the classroom as heavily dependent on the instructor and the information that is delivered by them. Some students also described this by saying: "So for the first exam I definitely looked at the discussion quizzes, because I think the professor wrote those, I am not entirely sure [short pause] but the in-lecture activities looked them too, because they were written by him I think." Sandoval has argued that students' practices in class are different from their personal beliefs about science, even in an inquiry-based course. Practical epistemologies are beliefs students have about their own scientific knowledge building in the classroom, whereas formal epistemologies are epistemological beliefs about science that professional scientists have (Sandoval, 2005). Findings from this study are in agreement with Sandoval's work, supporting the statement that learning in classroom may enact a category of epistemologies for science, which we name "classroom epistemologies" and they differ, to various extent, from the formal epistemologies about science, or simply called science epistemologies.

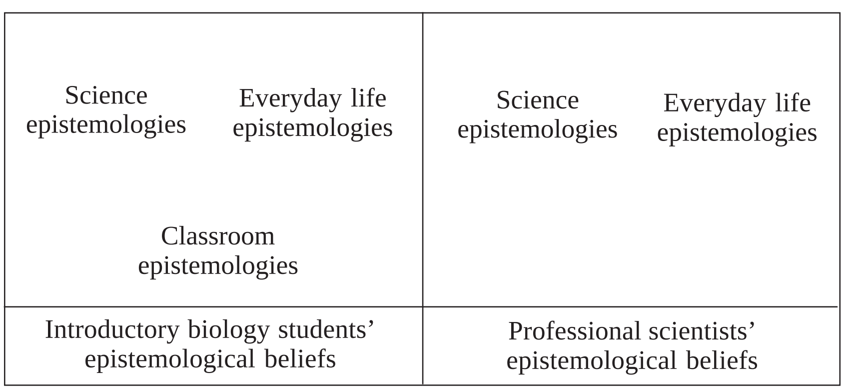


Figure 1. Comparative analogy of probable epistemological beliefs held by introductory biology students versus professional scientists

In this study, an obvious distinction between beliefs about biology learning and beliefs about scientific knowledge was seen in both the pre- and post- surveys. Specifically, we argue there are three main categories of epistemologies that college students might possess (Figure 1). First, they have science epistemologies –

or beliefs about "what real scientists do to produce evidence for a phenomenon." Second, they have everyday life epistemologies, personal beliefs about knowledge and learning in informal environments, at home, or places outside the classroom. Third, there are classroom epistemologies, beliefs students have about "what do I need to do to succeed in this course." These findings suggest that beliefs about success in class and beliefs about (biology) science are differentiated in students' minds and their educators may not be aware of this mismatch.

The instructors of the introductory biology course of this study were heavily interested in students' conceptual understanding. For this reason, the course exams were very concept-related and much less fact-related. Regardless of the instructors' efforts in the course exams, and the amount of in-class activities incorporated within lecture time, a lecture-based learning environment may not be appropriate for the development of student science epistemology. Regarding final exam studying methods, students who responded to the follow-up questions recognized that memorization of facts wouldn't have helped them succeed in this course and a lot of studying time was needed to understand the material. The students talked about drawing on whiteboards, or explaining biological processes/phenomena to their friends, or that they "tried to connect stuff from lecture to lecture." In particular, one student mentioned: "I combined all the stuff from the circulatory system and the different systems and tried to connect them, so I can make connections in my mind and then I explained it in my own words." These attitudes are all supporting the belief of connectedness in biological knowledge, however, achieving this in an introductory biology course may not always seem practical in the students' minds.

Introductory Biology courses should provide students with the epistemological resources necessary to build their favourable beliefs for science and align those to the ones for biology learning. Biology instructors need to be able to measure their students' epistemic beliefs and adjust their course syllabus according to the results. Unfortunately, this is a rather undeveloped area of research in biology education. We have made a lot of progress in teaching scientific content and lab skills, however, these cannot suffice for scientific skills development, without proper (favourable) epistemological beliefs for science.

CONCLUSION & LIMITATIONS

The findings of this study showed that first-year college students have various beliefs about biology knowledge and biology learning, with the latter heavily related to their classroom experiences. Those expectations, however, do not seem to align with those of their instructors (favourable ones) and they do not seem to shift to more favourable ones by simply introducing active learning in lecture. Because of the misalignment between epistemological beliefs about science and learning biology, students may prioritize their work on meeting the classroom expectations, which negatively impacts their authentic learning early in the beginning of their college education. Given the importance of these epistemologies on student learning, we must consider the question of how educators should introduce content along with professional science epistemology, with the goal of shifting and eliminating students' classroom epistemologies (Figure 1).

This study was conducted during a single semester with students from one biology course, thus the findings may not be representative of all US college biology students. Although measurements were taken to eliminate unintentional responses, there is always a chance that a percentage of responses may not reflect the true beliefs of students. To the best of our knowledge, no statistical validation of MBEX survey is available, which may be needed before using it in different learning environments than the original one.

ACKNOWLEDGMENTS

We would like to thank the introductory biology staff, who helped us collect these data and student consent. We are also grateful to Dr. Rosemary Russ, for her feedback, which greatly improved the quality of this study.

REFERENCES

American Association for the Advancement of Science. (2011). *Vision and Change in Undergraduate Biology Education: A Call to Action.* Washington, DC: American Association for the Advancement of Science. Available at: http://visionandchange.org/files/2011/02/Vision-and-Change-low-res.pdf

Barnett, J.E., Francis, A.L. (2012). Using higher order thinking questions to foster critical thinking: a classroom study. Educational *Psychology, 32*(2), 201–211.

Butler, H.A., Dwyerb, C.P., Hoganb, M.J., Francoc, A., Rivasd, S.F., Saizd, C., Almeida, L.S. (2012). The Halpern critical thinking assessment and real-world outcomes: cross-national applications. *Thinking Skills and Creativity 7(2),* 112-121.

diSessa, A. (1993). Towards an epistemology of physics. *Cognition and Instruction, 10(2-3),* 105–225.

Flores, K.L., Matkin, G.S., Burbach, M.E., Quinn, C.E., Harding, H. (2012). Deficient critical thinking skills among college graduates: implications for leadership. *Educational Philosophy and Theory, 44(2),* 212-230.

Hall, K. (2013). *Examining the effects of students' classroom expectations on undergraduate biology course reform*. Dissertation. Available at: http://drum.lib.umd.edu/bitstream/handle/1903/14080/Hall_umd_0117E_14168.pdf?sequence=1&isAllowed=y

Hammer, D., Elby, A. (2002). *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 169 – 190). Mahwah, NJ: Erlbaum Press.

Hammer, D. (2000). Student Resources for Learning Introductory Physics. *American Journal of Physics, 68*(S1), S52-S59.

Hofer, B.K. (2006). Domain specificity of personal epistemology: Resolved questions, persistent issues, new models. *International Journal of Educational Research, 45*(1-2), 85–95.

Hofer, B.K. (2004). Exploring the dimensions of personal epistemology in differing classroom contexts: Student interpretations during the first year of college. *Contemporary Educational Psychology, 29*(2), 129-163.

Hofer, B.K. (2001). Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review*, *13*(4), 353-383.

Hofer, B.K., Pintrich, P.R. (1997). The Development of Epistemological Theories: Beliefs About Knowledge and Knowing and Their Relation to Learning. *Review of Educational Research*, *67*(1), 88–140.

Mollohan, K. (2015). Epistemologies and Scientific Reasoning Skills Among Undergraduate Science Students. Dissertation. Available at: http://adsabs.harvard.edu/abs/2015PhDT.......265M

Momsen, J.L., Long, T.M., Wyse, S.A., Eber-May, D. (2010). Just the Facts? Introductory Undergraduate Biology Courses Focus on Low-Level Cognitive Skills. *CBE Life Science* Education, *9*(4), 435–440.

National Research Council. (2012). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Sandoval, A. (2005). Understanding Students' Practical Epistemologies and Their Influence on Learning Through Inquiry. *Science Education*, *89*(4), 634–656.

Schommer-Aikins, M. (2004). Explaining the Epistemological Belief System: Introducing the Embedded Systemic Model and coordinated research approach. *Educational Psychologist*, *39*(1), 19-29.

ISBN: 978-81-941567-9-6
January 3-6, 2020

INFORMAL LEARNING ENVIRONMENT TO COMMUNICATE SCIENCE: AN *OPEN DAY* EVENT AT THE INDIAN INSTITUTE OF SCIENCE, BANGALORE

Surabhi Kulkarni[1], Athavan Alias Anand Selvam[2*], Vinay Bapu Ramesh[3] and Hotha Srinivas[4]
[1,2,3]Prayoga Education Research Centre (PERC),
[4]Indian Institute of Science Education and Research, Pune
[2]athavan@prayoga.org.in

In the present work, we have discussed the hands-on activities and games performed in an "Open Day" event at the Indian Institute of Science, Bangalore. The participants are students from various academic institutions and the general public. The volunteers are chemistry teachers and educators from various organizations and institutions. In the view of celebrating the international year of the periodic table (IYPT-2019), participants were exposed to three different games which were designed based on the periodic table and Bohr's atomic model. During this event, the volunteers explained the history of the periodic table, the importance of IYPT-2019 and the game rules to the participants. Both the card and board games entertained the players with active participation and also resulted in effortless learning. In order to extend the knowledge about IYPT-2019, all the participants and winners were rewarded with pocket-size cards, charts, and books related to the modern periodic table.

INTRODUCTION

Science communication is emerging as a favored approach for communicating science both in a formal and informal way to the audiences/participants. Effective science communication is crucial to spread scientific thoughts and to develop an interest in science learning especially among young students (Burns, O'Connor, & Stocklmayer, 2003). It has also helped the general public familiarize with the basic principles of science and appreciate the contribution of science to everyday life. During the sixteenth and seventeenth centuries, science communication aimed mainly to engage the audience in wonderment and surprises (Knight, 2002). In late 1700, the Royal Institution was founded, which became the center for spectacular scientific lectures and was very popular among the upper classes of the community. Most popular lectures were delivered by experts like Humphry Davy, Michael Faraday, John Tyndall, and Henry Huxley. Even today, evening lectures and Christmas lectures are delivered to communicate science at the Royal Institution, London. (James, 2002; Austin and Sullivan, 2018). By the twentieth century, science demonstrations moved from learned class to include people from all the strata of society by introducing planetariums, exhibitions, science workshops, and museums to disseminate the ideas of science.

The environment of science learning is broadly classified into two ways, formal and informal learning. The formal learning environment is a traditional lecturing format which is largely present in schools, colleges, and universities. The informal learning environment is non-structural learning which includes a broad array of settings like museums, exhibitions, science shows/demonstrations, theatres, media programs, botanical gardens and other activities to transmit knowledge. A growing literature shows that students learning in a formal setup find science to be a difficult subject (Johnstone, 1991; Reid, 2008). Among the various scientific disciplines, chemistry is largely considered as a tough subject due to the nature of the subject itself. (Taber, 2001; Tumay, 2016; Alsop and Watts, 2003). Certain topics like atomic structure, the periodic table, mole concept, chemical bonding, and chemical equilibrium are considered as threshold concepts for high school students (Johnstone, 2010; Johnstone and Kellett, 1980). A plethora of research shows that using educational games will be fun, interesting, motivating and captures students' attention for a longer duration (Franco-Mariscal, Martínez, & Maìrquez, 2012; Franco-Mariscal, Martinez & Mairquez 2016; Martí-Centelles and Rubio-Magnieto, 2014; Tan and Chee, 2014).

In this paper, we discuss the activities performed in an informal learning environment known as '*Open Day*' event which is organized by the Indian Institute of Science (IISc), Bangalore every year (https://www.iisc.ac.in/events/iisc-open-day-2019/). IISc, a premier research institute opens its doors for the public every year on an open day event and this tradition has been followed since 1956 till date. The aim of this event is to showcase the research undertaken in the institute and to communicate important scientific concepts to the general audience. The year 2019 being the international year of the periodic table (https://www.iypt2019.org/), we had a stall during the open day event (March 23, 2019) to engage students/participants with some chemistry games. These games engage students in an interactive, enjoyable learning environment and also foster conceptual understanding. The activities included card games, board game, and a crossword puzzle which helped participants to realize that the invention of the periodic table is one of the most significant achievements in science. The students from various schools and colleges actively participated in our designed games. In an effort to encourage learning about the periodic table and atomic structure, all the participants and winners were rewarded with different prizes.

METHODS

Understanding the structure of the periodic table gives the ability to make predictions concerning atomic size, ionization energy, electron affinity, electronegativity, melting point, *etc.* about different elements (Rouvray, 2004). About four optimized games based on the periodic table and Bohr's atomic model were introduced to the participants during IISc open day event (Figure 1). The objectives of those games were as follows:

- To recognize the name, symbol, group and period of the elements in the periodic table.
- To recall the chronology of various periodic tables till the modern periodic table.
- To understand the electronic configuration and distribution of electrons in an atom.
- To correlate electronic configuration and the periodic table classification.

Figure 1: Game materials for the participants (a) *ChemDom* - card game (b) *ChemUno* - card game (c) *ChemUdo* - board game and (d) Elements name searching puzzle game

Games rules

The card games such as *ChemDom, ChemUno* were designed based on the periodic table and the board game *ChemUdo* was developed to explain Bohr's atomic model. Both the card and board games were designed to enhance students' engagement and motivation towards the learning goals and not by following any pedagogy. The rules and methods for each game are given below.

(i) *ChemDom:* *ChemDom* is a card game for 2-10 players. There are 118 cards in a deck that corresponds to the elements of the Periodic table. Each card is printed with the symbol, name, electronic configuration, block that it belongs to the periodic table, atomic number, period and group of an element with a *hypothetical* rank. Hypothetical rank is a random number given to each card. It is an independent variable and there is no correlation between other variables mentioned. The objective of this game is to recognize the name of the element, its symbol, electronic configuration, period, group and atomic number. The game begins by equally distributing cards among all the players. The player on the right side of the person who has distributed cards will start the game. The players will look at the above first card and declare one of the five variables (atomic number, period, group, block, and rank) in that round of the game. Subsequently, all the players will be showing their cards. The person with the highest value will be winning that round. However, if the variable is rank, then the participant with the lowest value will be winning that round. The order for blocks is s<p<d<f. All the cards that were displayed will be taken by the winner. The process goes on until one player remains with a maximum number of cards.

(ii) ***ChemUdo*****:** *ChemUdo* is a board game that can be played by a maximum of four players. The Game set includes the mainboard, 36 small display cards, dice, 16 e-cones (pawns) of red, blue, green, and yellow colors. The objective of this game is to understand the Aufbau principle and Pauli's Exclusion Principle. Each player will pick and display a card, which has the name, atomic number and electronic configuration of an element. The participants will choose four e-cones of identical color and the game begins with a person who gets the highest atomic number by rolling dice. Players are required to get either six or one to enter the home (center) for each e-cone. Eventually, the game continues the anti-clockwise direction. E-cone degeneracy will not be allowed in any orbital except s orbital. Each player will be commencing the game to complete the electronic configuration of the chosen element. The player who completes the electronic configuration of all the chosen elements of all participants will be considered as a winner.

(iii) ***ChemUno:*** *ChemUno* is a card game that is very similar to *the UNO* game for 2-10 players. The objective of this game is to recognize element symbol, atomic number, group, period and general properties of elements. There are 103 cards in the deck. Cards are of four different colors red, blue, green and yellow. There are two types of cards: number cards and action cards. Number card consists of the element name, symbol, atomic number, group and period of an element. Besides the Number cards, there are several other cards that help mix up the game. These are called action cards with five different actions and the descriptions of action cards are given below.

(a) ***Reverse*** – When a player gets a Hg or Br card, the clockwise direction game switches to counterclockwise or vice versa. This is to convey to participants that only Hg and Br elements are in the liquid state at standard temperature. (b) ***Skip*** – When a player places inert gas cards (He, Ne, Ar, Kr, Xe, Rn), the next player has to skip their turn. This will make participants understand that these gases do not react with any other elements. (c) ***Draw Two*** – When a participant discards a semi-precious element (like Ag & Cu) the next person will have to pick up two cards and forfeit his/her turn. From this, the students come to know that these elements are costly but not exorbitant. (d) ***Wild*** – This card represents all four colors, and can be placed on any card. The player has to state which color the card represents for the next player. This rule followed to convey to students that these elements are versatile and they react with most of the elements known. (e) ***Wild Draw Four*** – This acts just like the wild card except that the next player also has to draw four cards as well as forfeit his/her turn. This is to convey to students that these elements are very exorbitant in cost.

After shuffling, 7 cards are distributed to each player and they are dealt face down. The rest of the cards are placed in a draw pile face down. The top card should be placed in the discard pile, and the game begins! The game usually follows an anti-clockwise direction and all the players should try to match the card either by period, group or block (color) in the discard pile. Besides the card and board games, a crossword puzzle (element names) game was created to engage participants who are not familiar with the atomic structure and periodic table properties.

RESULT AND DISCUSSION

Students, parents, and teachers from various schools and colleges attended the "Open Day". Approximately

25,000 - 30,000 people visited the event at IISc. We designed our stall in association with the chemistry department of IISc to engage 40-50 participants in a batch. In the stall, 3 sets of each game were facilitated by 10 volunteers to participants aged above 12 (Figure 2). The role of volunteers is to undertake two major tasks - one of them is to facilitate games, and another is to provide logistics for distributing prizes and participatory gifts to the players. The volunteers introduced all the games to the participants by describing the theme of IYPT-2019, followed by questions pertaining to the periodic table and the atomic structure. The students were allowed to choose games randomly with their peers and also others.

As described in the introduction, game-based learning is a technique to motivate students to learn and understand concepts in an interesting way. The designed card and board games showed positive impact on the students' perceptions towards learning chemistry. Many students expressed their interest to learn all the chemistry concepts through a game-based approach. The participants enjoyed all the activities and some of the students showed competitive behavior while playing games. In comparison to the general public, school students quickly developed an interest in all the games. Initially, the volunteers asked a few basic questions to examine the acquaintance of the participants with the periodic table, periodic properties of elements and its electronic configuration. The common questions asked to all the students during the activities are given below.

- What is the periodic table?
- Are you familiar with IYPT-2019?
- Can you write the electronic configuration of any element?
- What do you know about subatomic particles?
- Do you know how the elements differ in properties?
- Do you know the shapes of s, p, d, and f orbitals?

Figure 2: IISc Open Day activities (a) Participants actively engaged with games, (b) & (c) Volunteers explaining card and board games, (d) Young participants deeply involved in the word puzzle game, (e) pocket size and chart periodic table for the participants, (f) The periodic table handbook for winners

Specific questions were asked to identify the alternate conceptions of the students who enrolled in pre-university and undergraduate courses. The volunteers collected data to test our hypothesis that the majority of the students lack knowledge on certain key facts and/or do not possess conceptual understanding of periodic table and atomic structure. A few example questions are - *"How are the elements arranged (in terms of atomic properties) in the periodic table? Which is the smallest element by size? What is the physical state of bromine at room temperature?"* and so on. For the first question, we observed an erroneous thought among a lot of students that *"elements are arranged in the increasing order of atomic size"* which was rectified by the volunteers. We also observed there exist a confusion between atomic mass and atomic size among students. Therefore some of them are wrongly relating the number of electrons to the atomic radius: *"Hydrogen has the smallest radius because it has only one electron"*. For the second question, some of the students answered wrongly that *"Hydrogen is the smallest element by size"*. Most of the students answered correctly as helium but without any explanation indicating the answer might have been memorized or guessed. Later during the gaming sessions, the facilitators explained the nuclear charge differences between hydrogen and helium to improve their understanding. The common misconception for the third question was, *"Bromine is a gas at room temperature like fluorine and chlorine"*. Playing with '*reverse*' active cards in *ChemUno* game, the players came to know that bromine and mercury are in liquid state at room temperature. It came to our notice that some students erroneously thought, *"there is no relation between the number of electrons and the chemical behavior of an atom"*. Later by the descriptions of active cards in *ChemUno* game, volunteers made clear the relationship between the outermost electrons and the chemical properties of some elements. By playing *ChemDom* card game, the students got familiar with the Greek names of the elements. From the students' response which were collected after the gaming sessions, we imply that the constant playing of both *ChemUno* and *ChemDom* card games will help in identifying group, period, atomic number and properties of most of the elements. The *ChemUdo* was identified as the most interesting game among students. Many students expressed that they could identify most of the modern atomic theory concepts in the board game. With *ChemUdo* game, the volunteers explained the application of electronic configuration in determining the period and group of the element without looking at the periodic table. The students asked some significant questions like: "*What is the difference between orbit and orbital?, What is the importance of electronic configuration?, How to write electronic configuration for cations and anions?, What is an unpaired electron?*", and so on. Based on the questions asked by the students, the volunteers explained Pauli's exclusion principle, Hund's rule and Aufbau principle to enable them to play the game. Furthermore, the anomalous electronic configurations of some transition elements such as molybdenum, copper, palladium were also informed during the board game session. It was observed that *ChemUdo* board game aid students to write electronic configuration of elements and improves conceptual understanding of atomic structure. The common students' misconceptions about the periodic table and atomic structure are listed in Table 1.

The main instrument used to evaluate the effectiveness of the games was a survey. After completion of each game, the volunteers interacted with the participants to get feedback about the games and effectiveness in learning concepts. Survey statements from the students were categorized based on their perceptions: the benefits of playing games for learning chemistry, the difficulty or simplicity of the game rules, and their motivation level in participation. Most of the students reflected with positive statements like: *"It is useful to learn effortlessly"*, *"These games support me to learn about less familiar elements"*, *"I like to learn all*

No.	Questions asked	Sample Responses (Verbatim)
1	How the elements are arranged in the periodic table? (in terms of atomic properties)	- *Based on its atomic size.* - *Arranged by atomic weight.* - *Based on its chemical behaviour.*
2	Which is the smallest element by size?	- *Hydrogen atom is the smallest because it has only one electron.*
3	What is the physical state of bromine at room temperature?	- *Bromine is a gas.* - *Gas like fluorine and chlorine.*
4	Is there is any element which don't follow Aufbau principle?	- *All elements follow Aufbau principle.* - *Yes. Radioactive elements don't follow.*
5	What is the correct electronic configuration for Na^{2+} (Z=11)?	- $1s^2 2s^2 2p^6 3s^1$ - $1s^2 2s^2 2p^4 3s^1$
6	Do all the elements have electrons, protons and neutrons?	- *Yes. All elements are made up of three sub-atomic particles.*

Table 1: Students' misconceptions about periodic table and atomic structure

the chemistry concepts through games", "I would like to purchase the game kits to play at home" etc. Some students felt difficulty in following the rules of *ChemUdo* game due to lack of coherent understanding of Aufbau principle, Pauli's exclusion principle, Hund's rule and the difference between orbit and orbitals. Later it was resolved by clarifying all the doubts during the gaming sessions. We observed that the designed games helped the students to overcome their misconceptions. To encourage more participation, pocket-size cards/ posters of the periodic table were issued to all the players (Figure 2). The winners of each game were appreciated with "*The Periodic Table Handbook*" written by Prof. C.N.R. Rao and Indumati Rao. Many teachers and parents responded positively about the gaming sessions and also inquired the availability of game sets to purchase. Some teachers commented that this was their first experience of using games to teach chemistry concepts. By viewing the responses from the parents and the teachers, we suggested that similar educational games can be used in a formal learning environment. However, the teacher needs to understand the objective of the games thoroughly and be able to achieve the required learning goals. We emphasize that there is a strong need for creative educational games like *ChemDom*, *ChemUno*, and *ChemUdo* in formal learning environment because it can be used to monitor the learning process of the students constantly. We also recommend that these games can be used in similar informal learning environments like science exhibitions, workshops, and other science community gatherings with appropriate audience.

CONCLUSION

Informal learning is a great approach to motivate students towards the learning process. All the participants enjoyed the autonomy associated with the IISc-open day event. The activities conducted by us as a part of the Open Day event helped school students to gather knowledge about IYPT-2019 and its importance. Many curious individuals showed deep involvement in solving puzzles, playing games and engaged in constructive interaction with the volunteers. The games and interactions allowed the facilitators to clarify certain common misconceptions in chemistry. This informal learning environment using games facilitates engagement in science learning and also enhances the academic performance of students. The entire program was successfully carried out to communicate science to all learners. There is a plenty of scope to conduct research on informal learning approaches and also incorporating game based pedagogies for various chemistry concepts.

ACKNOWLEDGMENTS

The authors thank Mrs. Nusrat, Mrs. Haseena Roshan, Mr. Subhas Chindanur, Ms. Anusha Dattatreya Manganahalli, Mrs. Alice Philip, Mrs. Jaya P. Swaminathan and Ms. Bhakti Dhamdhere for volunteering the event. The authors would like to extend their thanks to the Royal Society of Chemistry (RSC), United Kingdom for the funding.

REFERENCES

Alsop, S., & Watts, M. (2003). Science education and affect. *International Journal of Science Education, 25*(9), 1043–1047.

Austin, S. R. P., & Sullivan, M. (2018). How are we performing? Evidence for the value of science shows. *International Journal of Science Education, Part B, 9*(1), 1–12.

Burns, T. W., O'Connor, D. J., & Stocklmayer, S. M. (2003). Science communication: a contemporary definition. *Public Understanding of Science, 12*, 183–202.

Franco-Mariscal, A. J., Martínez, J. M. O., Blanco-Loìpez, A., & EspanÞa-Ramos, E. (2016). A Game-Based Approach To Learning the Idea of Chemical Elements and Their Periodic Classification. *Journal of Chemical Education, 93*(7), 1173-1190.

Franco-Mariscal, A. J., Martínez, J. M. O., & Maìrquez, S. B. (2012). An Educational Card Game for Learning Families of Chemical Elements. *Journal of Chemical Education, 89*(8), 1044–1046.

Indian Institute of Science, Open Day event - https://www.iisc.ac.in/open-day-when-iisc-unveils-its-research-to-the-public/

International Year of Periodic Table 2019 - https://www.iypt2019.org/

James, F. A. J. L. (2002). "Never talk about science,showit to them": the lecture theatre of the Royal Institution. *Interdisciplinary Science Reviews, 27*(3), 225–229. https://doi.org/10.1179/030801802225003178

Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning, 7*, 75-83.

Johnstone, A. H. (2010). You Can't Get There from Here. *Journal of Chemical Education, 87*(1), 22–29.

Johnstone, A. H., & Kellett, N. C. (1980). Learning Difficulties in School Science Towards a Working Hypothesis. *European Journal of Science Education, 2*(2), 175–181.

Knight, D. (2002). Scientific lectures: a history of performance. *Interdisciplinary Science Reviews, 27*(3), 217-224.

Martí-Centelles, V., & Rubio-Magnieto, J. (2014). ChemMend: A Card Game To Introduce and Explore the Periodic Table while Engaging Students' Interest. *Journal of Chemical Education, 91*(6), 868–871.

Reid, N. (2008). A scientific approach to the teaching of chemistry: What do we know about how students learn in the sciences, and how can we make our teaching match this to maximise performance? *Chemistry Education Research and Practice, 9*, 51-59.

Rouvray, D. H. (2004). Elements in the history of the Periodic Table. *Endeavour, 28*(2), 69–74.

Taber, K. S. (2001). Building the structural concepts of chemistry: some considerations from educational research. *Chemistry Education Research and Practice In Europe*, *2*(2), 123–158.

Tan, K. C. D., & Chee, Y. S. (2014). Playing games, learning science: Promise and challenges. *Australian Journal of Education in Chemistry, 73*, 20-28.

Tümay, H. (2016). Reconsidering learning difficulties and misconceptions in chemistry: emergence in chemistry and its implications for chemical education. *Chemistry Education Research and Practice, 17*(2), 229–245. https://doi.org/10.1039/c6rp00008h

A STUDENT-CENTRIC APPROACH FOR DEVELOPING SCIENTIFIC COMMUNICATION SKILLS IN UNDERGRADUATE MICROBIOLOGY STUDENTS

Aparna Talekar, Vivien Amonkar and Karuna Gokarn*
St. Xavier's College (Autonomous), Mumbai
karuna.gokarn@xaviers.edu

Scientific Communication is an important skill which needs to be developed in students for building a successful career in science. Here, we report the design and development of a student-centric, activity-based course in scientific communication skills (SCS) for undergraduate Microbiology students. We followed a pedagogical strategy that allowed for integration of assessment with the learning activities. The effectiveness of the course was measured by administering questionnaires to the students both before and after the course. The comparison between the results of the pre- and post-intervention questionnaires revealed that the students demonstrated an overall increase in their understanding of key concepts essential for SCS after undertaking the course. This report, even though preliminary, highlights the importance of developing a student-centric course in SCS at the undergraduate level.

INTRODUCTION

Proficiency in scientific communication is an important goal of undergraduate science education. As tertiary level science degree programs form the foundation of the life sciences sector by providing skilled manpower, it has been proposed that formal communication in science courses be introduced at this early stage of career development (Anderson & Helms, 2001; Spektor-Levy, Eylon, & Scherz, 2009). The major aim of such courses is to enable students to develop an ability to locate and retrieve relevant information, to critically evaluate information; to analyse and organize the information; to draw inferences based on evidence; and to be able to disseminate the acquired knowledge in an appropriate form by different modes of communication (NRC, 2012; McComas, 2014). Besides, a course in Scientific Communication Skills (SCS) may also assist students to verbalize their understanding of a subject matter for themselves and self-evaluate their own learning (Murray & Hughes, 2008). However, it has been observed that STEM students often find communicating 'science' a challenging task and traditional courses fail to build the necessary skills required (Grant, Liu, & Gardella, 2015). Therefore, it is essential to develop a course which integrates learning activities incorporated with tasks that aid in understanding the concepts and terms of the subject matter, and at the same time, engage the student in acquiring skills required for communicating their learning (Hurd, 2000). In this regard, an SCS course was introduced to second-year undergraduate science students of St. Xavier's College (Autonomous), Mumbai University in June 2011. Initially, a semester-long, one credit (15 contact hour) course was developed as a series of hands-on activities purposefully designed for better conceptual understanding of the subject matter. The core syllabus of the SCS module offered in the third semester almost remained the same, however, the pedagogy was modified to be more student centric and activity based. The instructors noticed that just the theory of SCS was not enough for the students to understand and apply the concepts of SCS. Thus, the SCS course module was modified and extended to Semester 4 where the students were asked to apply the skills in writing their laboratory projects (proposal, poster, project report, manuscript and presentation) which is evaluated as a part of SCS course.

Here, we elaborate upon the course design and its impact on students evaluated by a questionnaire administered to the students both before and after the first half of the course. We also note the qualitative differences observed in the students' responses and how it has served as a feedback for evolving and improving the course over the last seven years.

METHODS

Course Design and Execution

The SCS course in Microbiology has been divided into six modules spanning over two semesters. While the focus of the earlier semester (third) is the comprehension of various aspects of scientific communication, the latter semester (fourth) deals with the application of the concepts learned.

The first module of the course requires that the students create mind maps on any Microbiology topic chosen by them (in consultation with the mentors) and convert it into a chart or a model to be presented in the annual exhibition organized for the orientation of the first-year Bachelor of Science students. One example of a mind map and the corresponding chart prepared by the student is shown in Figure 1 (Matthews & Matthews, 2008; Buzan & Buzan, 1993).

A. B.

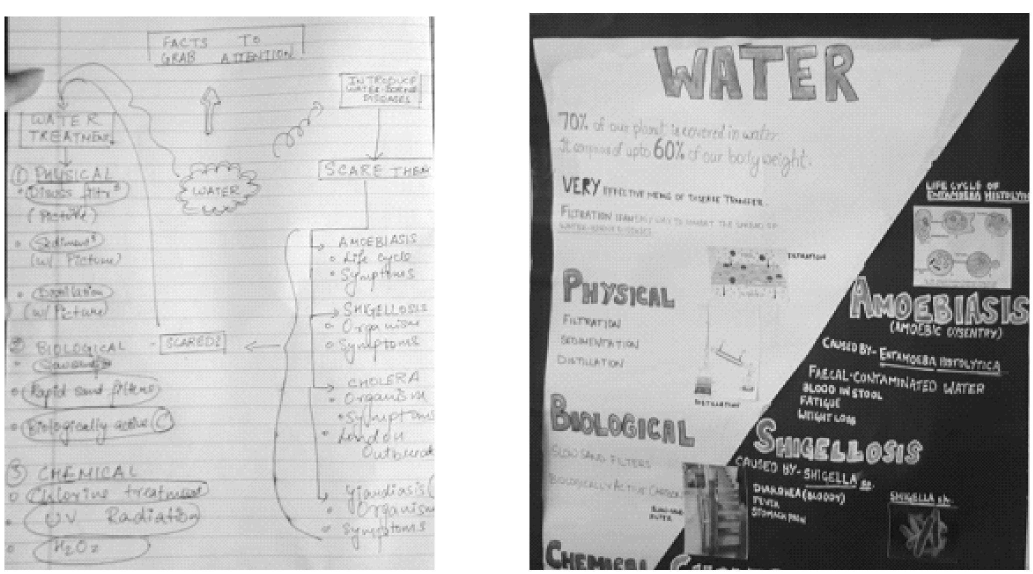


Figure 1: A) An example of a mind map prepared by a student B) shows the corresponding chart made by the same student.

This activity engages the students in researching the literature, retrieving the relevant information, organizing the information and finally verbalizing their assimilated knowledge. The effectiveness of mind maps in organizing information and developing knowledge structures has been established earlier (Buzan & Buzan, 1993) . The evaluation of this task is done by mentors who visit each exhibit (chart/model) and assess it for the relevance of content, comprehensiveness, and clarity. The students are also assessed for their verbal explanation of the chosen topic to the visitors/mentors. We have observed that not only does this task act as an ice breaker between the freshers and the sophomore students but it also develops a sense of self-efficacy among the second-year students.

The next module deals with comprehending technical information and summarizing it. The students are first sensitized to crucial elements of summary writing and then given short research articles or popular science commentaries (audio-visual) relevant to the discipline to summarize in their own words (word limit: 150). It has been reported that summarizing in their own words helps students in comprehension of new information which is an indicator of student learning (Haystead and Marzano, 2009). The difference between a summary and an abstract is also emphasized. The evaluation involves summarizing scientific information provided to students in the form of an audio-visual documentary or a science topic-based film. The use of varied modes of scientific information challenges the students with multisensory inputs and fosters comprehension skills that promote learning (Blomert & Froyen, 2010; Clark, Nguyen, & Sweller, 2006).

The next three modules were designed based on our observation that undergraduate students often struggle with understanding research articles and find it challenging to grasp technical information. Similar difficulties faced by students globally have also been reported (Goldbort, 2006). Proficiency in scientific communication necessarily requires understanding the elements of a good scientific report/research articles. Hence, students are initially introduced to components of a scientific write-up, generally a research article (Murray & Hughes, 2008). One of the most important aspects discussed in detail is ‘plagiarism’. Students’ difficulty with recognizing and understanding the concept of plagiarism is a challenge faced by educators worldwide (Dawson & Overfield, 2006). The concept was dealt with as a series of discussions with exemplars of plagiarism, paraphrasing, and citations extracted from several kinds of scientific literature. Students are also made aware of software available for detection of plagiarism (eg: Turnitin and a free tool available online-SEO plagiarism checker). The idea is to sensitize students to the importance of maintaining academic integrity and avoiding plagiarism. Further, the students are introduced to various sections of a primary research article and familiarized with the IMRaD format (Sollaci & Pereira, 2004). Students are then engaged in a group reading exercise where they try to understand a simple research paper by paying attention to its title, abstract and other sections up to the references as per the standard guidelines (Hoogenboom & Manske, 2012). Generally, the instructors ensure to give research articles from different peer-reviewed journals to familiarize the students to the fact that different journals may follow slightly different formats. This is followed by a discussion of the papers read (2-3 papers) in the class by the groups to share their perspectives with their peers. The papers assigned to the class are usually chosen from the field of Microbiology and mostly have methodologies familiar to students. The final learning task of the course in this semester is critiquing a research paper which is carried out as a group discussion activity moderated by the instructor. The students are divided into groups of 10-12 students and allowed to read and discuss 2-3 papers. This interpersonal exchange of ideas encourages peer learning, teamwork and developing soft skills of a student (Besley & Tanner, 2011). Students are also introduced to allied concepts such as peer review, open access articles and bibliometric databases such as Web of Science and Scopus. The final evaluation for this course involves writing a critical review of a research paper from a journal for them to understand the importance of publishing in peer-reviewed journals. All the aspects learned throughout the semester are assessed in this activity such as students' attention to the relevance of the title, comprehensiveness of the abstract, appropriate literature citations, checking for plagiarism and referencing style. The advanced part of this course is dealt with as an integrated activity with the disciplinary research projects undertaken by students in the next semester (fourth). The students are introduced to literature reviews, referencing styles, reading different types of research reports and other activities. The students write their own project proposals before embarking upon the research projects which are ratified by the mentors. The learnings from both the semesters culminate in the form of a scientific report, a poster and an oral presentation for summarizing their work which forms a part of an assessment for the SCS course.

Participants

The SCS course typically accommodates 33-37 student participants for this study, per year. The students belong to the second year of Bachelor of Science course in Microbiology with an average age of 19 years. The course spans 2 semesters of the year. The number of credits is one per semester and the number of contact hours is 15 per semester.

Questionnaire Design

The course in SCS started in 2011. Although the need for an SCS course was apparent, we began to ponder over the effectiveness of the course after a few years of its inception. We took oral/written feedback from the students to assess the efficacy of the course. In order to formalize the assessment, a questionnaire was designed to evaluate the impact of the course on the students during the last year. The questionnaire was designed based on the modules and what the students are expected to know after the course was completed. Since most students joining the course come with little prior knowledge or familiarity with the topic, the questionnaire comprised of questions about general aspects of scientific communication and was administered to students before the beginning of the course (before the third semester designated as pre-intervention questionnaire) to gauge a baseline understanding of the students for the topic. The students are given 30 min for answering the questions. The questionnaire was also administered at the end of Semester 3 (after the end of the first half of the course designated as post-intervention questionnaire). Over the years, the questionnaire has evolved based on the responses of the students. A sample of the common questionnaire used in the study is given in Table 1.

The questions were purposefully designed to be open-ended in nature to serve as a formative assessment and provide an insight into alternative conceptions of the students. As detailed earlier, in the third semester, the students are exposed to activities for comprehending various aspects of scientific communication while in the fourth semester, they apply all their learning to write a research report. Therefore, a similar questionnaire is administered again to the students at the end of the fourth semester to assess whether the reiteration of concepts leads to the enhanced grasping of the topics. However, in this report, we only present examples from student responses from the questionnaire administered before and after the third semester.

Sr. No.	Question	Responses – Pre- intervention questionnaire	Responses – Post- intervention questionnaire
Q.1	Give an example of plagiarism. You may create one.	• Copy-pasting matter from the internet • Using research material without permission from the publisher • Don't know • Stealing someone's idea • Violating copyright	• When a researcher copy-pastes some writing from another paper • When something is written as it is without paraphrasing • A research paper published in one country has the same publication in another country in a different journal • Copying the same words
Q.2	What do you understand by paraphrasing? Explain with the example you have given as an answer to Q.1.	• To explain in one's own work • Summarising someone's work • Don't know • To reduce the size of a big paragraph • Gives credit to the inventor	• Modification of a sentence so that the meaning remains the same • Write a sentence in one's own words after understanding the essence of the given content • Understand the meaning and then write in one's own words • Rewriting in one's own words without the meaning being lost
Q.3	How would you differentiate between a review article and a research paper?	• A research paper talks about one's discoveries, whereas, review article you critique someone's paper • A research paper is writing about the experiment, whereas, a review article is one's opinion of a research article • Don't know • A research paper is scientifically proven, whereas, a review article is theoretical	• A review article is to critique a paper; research paper gives details • A review is like a summary of many research papers put together; research paper follows the IMRaD format • A review article is not in much detail; research paper gives all details • Review article does not follow IMRaD format; research paper does
Q.4	How is a summary different from an abstract?	• A summary is a scientific content; abstract is something which is thought by a person • A summary is a detailed explanation; abstract is a short mind map • A summary is a whole story or idea explained in short; abstract is all important points about the idea • A summary is something written in brief; abstract is a visual summary	• A summary is an overview of an experiment, abstract gives an idea of the paper • A summary can be written for an article, an abstract is written only for research papers • A summary is a discussion of the article in short. Abstract highlights the main points of the research paper • A summary is a shorthand version of a full-length article or paper; abstract is like a brief preview of the research paper
Q.5	If you were to write a reference for your research paper, how would you write it? Show this as an example of a reference.	• Don't know • Paper on ABC by Mr. X pgs- 1-2 • Not relevant • Write the page and article number and name of the paper	• Authors, XYZ, journal name • XYZ, authors, journal name • Authors, journal name, XYZ • Author surname, initials, year

Sr. No.	Question	Responses – Pre- intervention questionnaire	Responses – Post- intervention questionnaire
Q.6	Write down the subtitles you would use to write a proposal.	• Don't know • I did not understand • Not applicable • Theory abstract result conclusion	• Introduction, materials, and methods; applications, expected results • Introduction, materials, and methods; applications, expected results, the relevance of the project, budget • Introduction, materials, and methods; applications, expected results, budget, references

Table 1: Questionnaire with examples of pre-intervention and post-intervention Responses

Data Analysis

The responses obtained from the administration of the questionnaire was assessed qualitatively as well as quantitatively. The correct responses were designated as positive responses and the comparative data between the pre- and post-intervention questionnaire is presented as a bar chart (Figure 2). Further, a qualitative analysis was done of the student responses received both before and after the course which served as indicators of a change in student responses. Some randomly chosen responses from both the pre- and post-intervention questionnaire have been presented in Table 1.

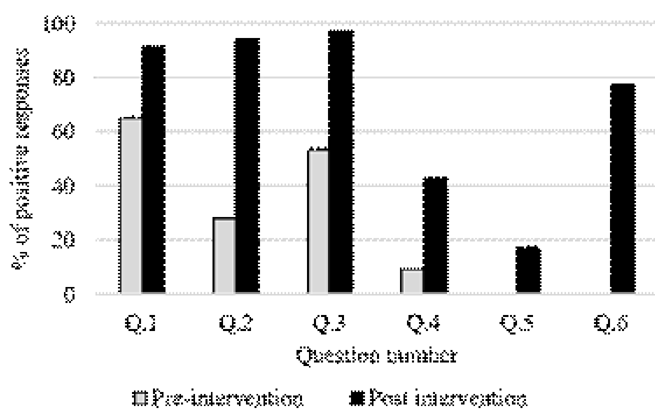


Figure 2: The percentage of positive responses obtained from the students for the administered questionnaire before (pre-intervention) and after (post-intervention) the course is represented on the Y-axis while the number of the question is represented on the X-axis.

RESULTS AND DISCUSSION

The percentage of positive responses obtained by administration of the pre- and the post-intervention questionnaires to students is presented in Figure 2. An overall increase in the number of positive responses was observed across all the six questions. The maximum increase (77.14%) was observed for question number 6 while the lowest change (17.14%) was recorded for question number 5. It was noted that even though students were aware of the concept of plagiarism (Q.1), they did not know about paraphrasing (Q.2).

Most students associated paraphrasing with either shortening the length of the content, summarising the content or writing the same content but giving credit to the original author (Table 1). However, after the course, most students correctly stated the meaning of paraphrasing as writing the content in one's own words after understanding the essence of the original text. This aspect was dealt in the class with several examples of paraphrasing and extended discussions. Based on the formative assessments and feedbacks over the years, it was realized that merely apprising students about plagiarism did not help them in correcting their mistakes while active group discussions in class with varied examples remedied the problem. This was also evident in the examples created by the students as a response to Q.1. Almost none of the students could create an example for Q.1 in the pre-intervention questionnaire. Many did so in the post-intervention questionnaire. An example given by one of the students was "Plaque assay is much similar to viable count" stated as is as plagiarism and modified as "There are various similarities in viable count and plaque assay" for paraphrasing in Q.2. Another example given for Q.1 was "The cellulose degraders were isolated from soil samples and were enriched in MacBeth's medium" and modified as "Soil sample was used to isolate cellulase enzyme producers. MacBeth's broth was used to enrich them." for Q.2.Further, it was observed that students had minimal or no understanding of research articles in general. Most students did not understand the difference between a research and a review article (Q.3) or between an abstract and a summary (Q.4). Most students associated an abstract with a research article only after the course. Students also had minimal or no understanding of the concepts of reference writing before the course which increased marginally after the course (Q.5) (Table 1). However, it was noted that reference writing skills improved substantially after the fourth-semester course where the topic was dealt in much detail and they actually applied it to write the references in their project reports (data not shared in this report). Overall, a change in the vocabulary of the answers was observed where students' usage of technical terms increased in the responses after the course. The activity on critiquing of the primary journal article used for evaluation of module 6 of the course gave an insight into the learning of the students. A few students understood the abstract as something of a prelude to a journal article which does not necessarily outline results. Also, many students critiqued the absence of a detailed method for standard protocols which are generally cited as previous publications in most research articles. Additionally, most students only wrote about the negative aspects of the given article; although we did expect the students to appreciate the well-written portions of the articles too. Most of these issues are discussed with students in the next semester, though we also plan to address these with the next batch of incoming students in the third semester. Since, the students were not exposed to any course on scientific communication skills in their previous years of study, the changes observed in the students' understanding of the subject matter may be attributed to the SCS course module attended in the college.

LIMITATIONS OF THE STUDY

We recognized a lack of general communication skills in English in a few students which made it difficult for us to evaluate their understanding properly. Even though we realize that proficiency in English is a primary requirement for developing effective SCS, currently our course does not address the problem.

We started the course on SCS in the year 2011 with some modules which were activity-based. Every year we observed students, took their feedback and went on revising the course. It has been our observation that student learning improved as we went on designing activity-based classes. Even though we took feedback of the course every year both during the course and at the end of the course, we did not systematically record the student learning data over the early few years. The data that we present in this study is derived from the last year only. There is no quasi control for this study where a similar course without following activity-based methods was delivered and could be used for comparison. However, an elaborate study with an appropriate control group of students and using standard tools for measuring student learning as a proof of concept is now underway for the current year. The data presented in this report is preliminary and is part of the current ongoing study.

ACKNOWLEDGEMENTS

The authors would like to thank St. Xavier's College (Autonomous) for giving us the opportunity to teach SCS and for allowing us to present our work. We would also like to express our heartfelt gratitude to Dr. Deepti Gupta for all her inputs and help in the preparation of this manuscript.

REFERENCES

Anderson, R. D., & Helms, J. V. (2001). The ideal of standards and the reality of schools: Needed research. *Journal of Research in Science Teaching*, 38(1), 3-16.

Besley, J. C., & Tanner, A. H. (2011). What science communication scholars think about training scientists to communicate. *Science Communication*, 33(2), 239-263.

Blomert, L., & Froyen, D. (2010). Multi-sensory learning and learning to read. *International Journal of Psychophysiology*, 77(3), 195-204.

Buzan, T., & Buzan, B. (1993). The Mind Map Book How to Use Radiant Thinking to Maximise Your Brain's Untapped Potential. New York, USA: Plume.

Clark, R. C., Nguyen, F., & Sweller, J. (2011). Efficiency in learning: Evidence-based guidelines to manage cognitive load. San Franscisco, USA: John Wiley & Sons.

Dawson, M. M., & Overfield, J. A. (2006). Plagiarism: Do students know what it is? *Bioscience Education*, 8(1), 1-15.

Goldbort, R. (2006). *Writing for Science*. New Haven & London: Yale university press.

Grant, B. L., Liu, X., & Gardella, J. A. (2015). Supporting the development of science communication skills in STEM university students: understanding their learning experiences as they work in middle and high school classrooms. *International Journal of Science Education,* Part B, 5(2), 139-160.

Hoogenboom, B. J., & Manske, R. C. (2012). How to write a scientific article. *International Journal of Sports Physical Therapy*, 7(5), 512.

Hurd, J. M. (2000). The transformation of scientific communication: A model for 2020. *Journal of the American Society for Information Science*, 51(14), 1279-1283.

Matthews, J. R., & Matthews, R. W. (2014). *Successful Scientific Writing: A Step-By-Step Guide for The Biological and Medical Sciences*. Cambridge, UK: Cambridge University Press.

McComas, W. F. (2014). *The Atlas of Science Literacy. In the Language of Science Education* (pp. 9-9). Rotterdam: Sense Publishers.

Murray, N., & Hughes, G. (2008). *Writing up your university assignments and research projects: A Practical Handbook*. Maidenhead, UK: McGraw-Hill Education.

National Research Council. (2012). *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering*. Washington, USA: National Academies Press.

Sollaci, L. B., & Pereira, M. G. (2004). The introduction, methods, results, and discussion (IMRAD) structure: a fifty-year survey. *Journal of the Medical Library Association*, 92(3), 364.

Spektor-Levy, O., Eylon, B. S., & Scherz, Z. (2009). Teaching scientific communication skills in science studies: Does it make a difference? *International Journal of Science and Mathematics Education*, 7(5), 875-903.

DESIGNING COMPUTATIONAL MODELS AS EMERGENT SYSTEMS MICROWORLDS TO SUPPORT LEARNING OF SCIENTIFIC INQUIRY

Sugat Dabholkar[1]* and Uri Wilensky[2]
Northwestern University
sugat@u.northwestern.edu[1]

Emergent Systems Microworlds (ESMs) are a special kind of computational models. Design of ESMs involves a combination of two approaches in Learning Sciences, namely agent-based modelling of complex systems and constructionism. ESMs and ESM-based curricula are frameworks for designing learning environments to foster the learning of complex scientific phenomena by engaging students in authentic scientific inquiry practices. In this paper, we discuss our approach in the context of an ESM called GenEvo that we designed for the learning of molecular genetics and evolution. We further discuss how agent-based representations and constructionist design principles mediated students' expansive learning, as students collaboratively constructed knowledge by engaging in authentic scientific inquiry practices.

INTRODUCTION

The goal of science education should not be limited to 'knowing about science', rather it should include 'learning to use science practices and tools to make sense of the world' (Duschl, 2008; Schwarz, Passmore & Reiser, 2017). Such learning would entail epistemologically meaningful engagement in science practices for sense-making, rather than merely knowing about scientific inquiry (Lehrer & Schauble, 2006; Berland et al., 2015). In other words, students should learn to construct knowledge about the world, just like scientists do. In order to support such learning in classrooms, researchers and educators are increasingly designing newer technology-enhanced collaborative learning environments and curricula that are authentic to contemporary scientific inquiry practices and provide epistemic and conceptual scaffolds for learning those practices (Chinn & Malhotra, 2002; Quintana et al., 2004). We contribute to this work of designing for computer-based collaborative science learning by combining two powerful design approaches in learning sciences: agent-based modelling of complex systems and constructionism (Wilensky & Resnick, 1999; Jacobson & Wilensky, 2006; Blikstein & Wilensky, 2010; Wagh, Cook Whitt & Wilensky, 2017). We call this design approach Emergent Systems Microworlds (ESM) (Dabholkar, Anton & Wilensky, 2018).

In this paper, we discuss an ESM about genetics and evolution, and an ESM-based curriculum that has been specifically designed to foster students' learning of scientific inquiry practices. We use Cultural Historical Activity Theory (CHAT) to analyse ESM-mediated expansive learning of science (Engeström, 2001). This is a design-based implementation research paper, in which we discuss design features of ESMs and an ESM-based curriculum, and present empirical support for the claims regarding how these features foster learning of disciplinary ideas and scientific inquiry practices.

THEORETICAL FRAMEWORK

Emergent systems microworlds

ESMs are agent-based models of emergent systems that are designed as microworlds to support students' learning through explorations and investigations of those models.

Emergent complex systems perspective involves understanding how simple interactions between autonomous elements can result in complex emergent patterns at the system level (Jacobson & Wilensky, 2006). This perspective has become a focus of real-world scientific investigations as well as recent science education reforms (Yoon, Goh & Park, 2018). Researchers of science education have argued for and demonstrated the effectiveness of emergent systems perspective for understanding natural phenomena (Wilensky & Jacobson, 2015; Wilensky & Reisman, 2006; Hmelo-Silver & Azevedo, 2006). Next Generation Science Standards in the United States has incorporated 'systems and systems models' as one of the seven key crosscutting concepts (NGSS Lead States, 2013).

Agent-based modelling of emergent systems is one of the central design features of an ESM. Such dynamic computational agent-based representations are restructurations of emergent phenomena which are typically taught with differential equations or static models (Wilensky & Papert, 2010). The agent-based restructurations have been demonstrated to be pedagogically effective to support learning of several complex natural phenomena in science education (e.g. electric current, resistance, temperature, pressure, evolution) (Sengupta & Wilensky, 2011; Levy & Wilensky, 2009; Wagh et al, 2017). The agent-based modelling approach allows students to observe behaviours of agents, and reason about emergent patterns by reducing cognitive and perceptual limitations (Goldstone & Wilensky, 2008).

The Microworlds part of an ESM is inspired by constructionist design principles (Papert, 1980). We use the 'functional' definition of microworlds as being encapsulated open-ended computational exploratory environments in which a set of concepts can be explored, through interactions that lead to knowledge construction (Edwards, 1995). A learner is expected to manipulate objects and execute specific operations instantiated in a microworld. Such manipulations would result in observable changes in the microworld. As learners observe those changes, they receive feedback through representations linked with the objects about their behaviours and changes in the system. Learners use this feedback to induce or discover the properties and functioning of the system as a whole. Through this process, they learn by self-correcting or 'debugging' their understanding of the domain to develop new powerful ideas (Papert, 1980). Constructionist learning environments in the form of microworlds have been demonstrated to be effective for learning in several contexts (Kafai & Resnick, 2012; Noss & Hoyles, 2017).

ESM-based curricula

In an ESM-based curriculum, students explore and learn about scientific phenomena using ESMs. ESM-based curricula engage students in actively constructing knowledge in a computational microworld using scientific inquiry practices similar to those scientists use to construct knowledge about the real world. The computational microworlds are designed on the basis of current fundamental scientific paradigms (Kuhn, 2012). Every agent-level entity in the microworld follows the rules that are specified according to the current scientific principles. Also, emergent patterns are consistent with scientific understanding.

GenEvo – An ESM-based curriculum

The GenEvo curriculum incorporates a series of computational models designed using NetLogo (Dabholkar & Wilensky, 2016). NetLogo is an agent-based modelling software that has been used for research work regarding emergent systems as well as to design educational curricular units (Wilensky, 1999).

Figure 1: A student exploring intracellular molecular interactions in an ESM of a bacterial cell

In this curriculum, students are first presented with a computational model of a bacterial cell with a genetic circuit in which certain components such as proteins and parts of DNA interact in a specific manner. Students explore and play with the model to figure out these interactions and how they result in complex emergent behaviour at the cellular level. In the next two subunits, students explore and tinker with the models of genetic drift and natural selection. They observe competition between cells and reason about emergent patterns at the population level. Finally, students revisit the first model and engineer the genetic circuit to make their cells 'fitter' to reproduce. The cells where genetic circuits are designed by the students then 'compete for survival' in a limited resource environment.

All of the computational models in the GenEvo curriculum are designed using the agent-based perspective of modelling emergent systems. In each model, the agents and their behaviours at the micro-level are computationally coded. As agents interact with each other and with their environment, it results in emergent patterns at the macro-level (Wilensky & Resnick, 1999; Wilensky, 1999b). Students can observe both the interactions at the agent-level and patterns at the system-level. In this curricular unit, the emergent properties of biological systems include genetic regulation, carrying capacity, genetic drift and natural selection. Students work in small groups of two or three. Their explorations are scaffolded by guiding them to focus on specific aspects of agent behaviours, such as resource availability or DNA-proteins interactions. Students are asked to explore a model and identify its aspect that they find interesting to investigate. They are asked to state it as a research question and state their preliminary answer as a testable hypothesis. Then they design and conduct computational experiments in the ESM learning environment to test their hypotheses and present their investigations. Their findings collectively build towards ideas about the emergent properties regarding genetic regulation and evolution.

ESM-mediated Expansive Learning

We view ESM-mediated students' learning as expansive learning to understand the affordances of ESM-based curricula for mediating students' engagement with disciplinary ideas in the classroom community (Engeström, 2001) (Figure 2). Expansive learning is viewed in the context of an activity system, which includes tool and sign that mediate the relationship between a subject and an object, rules, community and division of labour (Figure 2a). Expansive learning produces culturally new patterns of activity.

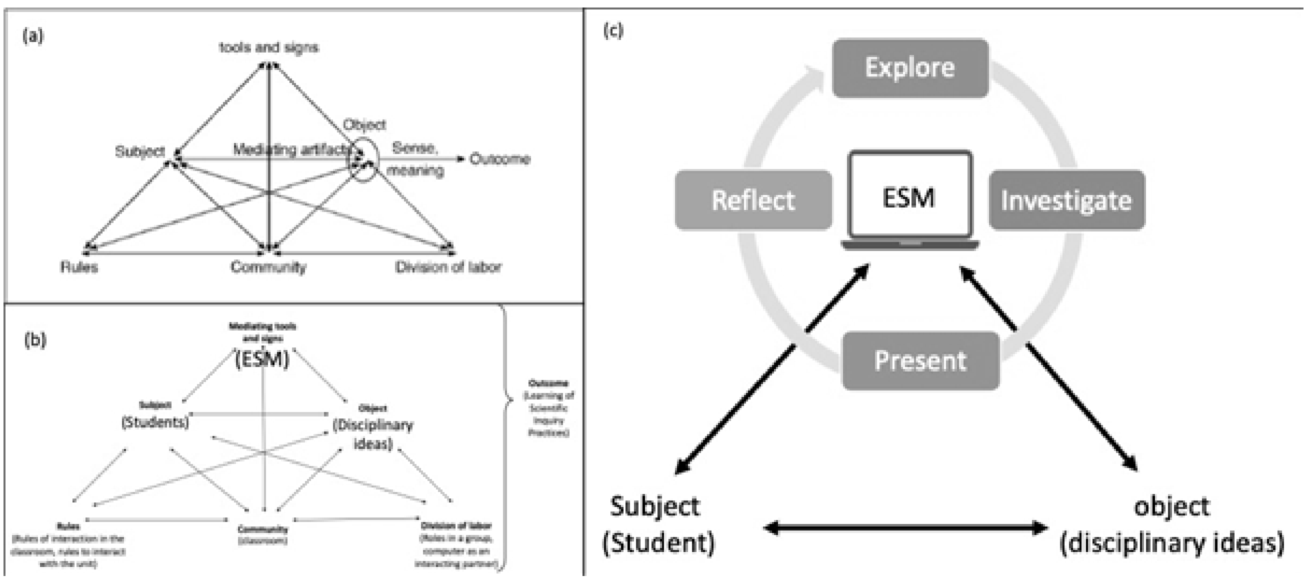


Figure 2: An ESM-mediated activity system (a) A second generation activity system that takes into account learning in the context of a community (Engeström, 2001) (b) ESM-mediation in an activity system in a classroom context (c) Various forms of student engagement with ESM.

In most classroom settings, the relation between the subjects (students) and the objects (disciplinary ideas) is viewed as students understanding the scientific knowledge that is provided to them by teachers and textbooks. Whereas, we expect that a computer-based ESM can potentially mediate students' expansive learning such that it would transform their relationship with disciplinary ideas. Our research question is as follows:

How does the design of ESM-based curricula mediate transformation of the relationship between the students and disciplinary ideas as they collaboratively construct knowledge?

METHODS

Research context

The data used in this paper is from a computational biology course that included the GenEvo curriculum. The first author of this paper was the lead-designer of the ESM and the curricular unit, and the lead-facilitator in these implementations. We use the data from the fourth iteration of the course. The first two iterations were in a weekend extra-school program for middle school students conducted by a talent-development centre in a mid-western university in the United States. The latter two implementations were in residential summer camps in a western city in India where students from all over India participated. The students that participated in both these programs were of age 11 to 14. In the fourth iteration of this design-based implementation research, 12 students participated of whom 5 were females, and 7 were males. All the students were of Asian Indian origin.

Data collection and analysis

We collected data in various forms, namely, extensive field notes by a field researcher in the class, videos of student discussions, workbooks in which students wrote their observations and explanations, the computational artefacts (models, screenshots and presentations). We also conducted pre- and post-tests, and pre- and post-interviews about their ideas regarding science learning and what scientists do. In the sections that follow, we use video data and data from pre- and post- interviews. We focus on interview questions that are about students' perceptions regarding the learning of science, especially from the perspective of understanding their agency in knowledge construction, and practices that scientists follow to construct knowledge. The question prompts were: *(1) Choose any topic that you learned in your science class/ in this course and explain how you learned it; (2) What do you think scientists do as their daily work?; (3) So, scientists construct knowledge about the world, right? How do they do that? How do they know that what they have figured out is right?* We used mixed-methods analysis to investigate how students talk about science learning and practices of scientists. The bottom-up, open coding was done using the constant comparative method (Glasser & Strauss, 2017). All the student responses were then coded by two researchers. Each student response was coded once for every category. The disagreements between the researchers were discussed and resolved until Cohen's Kappa value was greater than 0.7 for each category.

ANALYSIS

ESM-mediated expansive learning

In this section, we share our findings about how certain design features of ESM, specifically agent-based representations and constructionist design in the form of a microworld, fostered students collaborative expansive learning in a classroom context. In the GenEvo course, students worked in small groups. Each group constructed their contextual knowledge through their own investigations in the context of the ESM (Figure 2c). They identified their research questions, designed and performed experiments, and collected evidence. They presented their findings to the class. Other groups in the class questioned them, to seek clarifications and to provide counter-evidence that they may have found through their own investigations. Students iteratively went through this cycle of exploration, investigation, presentation and reflection (Figure 2c). Students were asked to give credit to other groups if they wanted to build on the ideas that were proposed and investigated by other groups. This is similar to how a scientific community cites works of other research groups to build collective knowledge.

Agent-based representations

An ESM provides agent-based representations to reason about emergent patterns in the case of a natural phenomenon. Such restructurations of emergent phenomena with dynamic computational representations improve the learnability of these complex ideas (Wilensky & Papert, 2010). The simplicity of these behavioural representations mediated students' sharing of ideas and allowed them to collaboratively figure out mechanisms of emergent patterns. When Vidya (pseudonym[1]), a rising 8th-grade student in India, was asked how she learned in the GenEvo course, she responded as follow:

> "(I learned) the cell's way of regulating production of specific proteins that are needed because they eat up some energy. Because every protein has its cost, so a cell has to know when it is necessary to make it and not just make it when it's not needed….. Because, it also degrades, so it's of no use….. So, the cell's way of doing that is to produce LacI, which is.... when there is no lactose, it can join with the DNA and it can prevent the formation of LacY and LacZ by RNAP, but when there is lactose, it is unable to do so, because it is blocked by the presence of lactose. (I learned it) by piecing something together. It just came to me, I guess! Before that we were discussing, the LacI and lactose binding thing…. I was wondering why this happened. And then *Sajid* (her partner) found out that when LacI is bound, the RNAP doesn't roll. Then I just thought of it." (Vidya's interview, May 2018)

What Vidya explained is how she learned an advanced emergent phenomenon of molecular genetic regulation. She did this by observing interactions of DNA and proteins as computational agents in the model by herself and building off of her partner's ideas. What Vidya is describing as *'the cell's way'* is an emergent phenomenon that manifests at the cellular-level because of biochemically constrained stochastic molecular interactions. In the conversation above, Vidya's use of *'the cell's way'* is a reference to emergent cellular behaviour from a class discussion. This had become a highly debated topic of discussion in the class, when Vidya explained to the rest, how these *random interactions* would result in emergent sensory behaviour of a cell.

Constructionist design

In the GenEvo course, the students learned emergent ideas by manipulating behaviours of computational agents and investigating system-level effects of those manipulations manifested in the microworld. Since every student used the same microworld, they developed a shared language to talk about those computational objects. These agent-level representations were 'object-to-think-with', which allowed students to collectively reason about emergent properties (Papert, 1980). This is how Sajid, Vidya's partner, investigated computational representations of proteins as objects-to-think-with to reason about a cellular behaviour.

"I was observing (potato-shaped things). So first I observed that it was just random movement. Then I saw that it was going on a straight line (on DNA), so I saw that it was rolling along the DNA. And then suddenly, when it went off pink triangles and rectangles were produced. I did this experiment 2 or 3 times and then I figured out that the RNAP produced LacZ and LacY…." (Sajid's interview, May 2018)

Sajid made an observation about a pattern that was related to the production of proteins, which were

[1] All the names used in this paper are pseudonyms.

represented as *pink triangles and rectangle*s pertaining to the movement of RNA polymerase (represented as a *potato-shaped thing*). He hypothesised that the movement of RNA polymerase on DNA is related to protein production. He verified it by repeating the experiment a few times under the same conditions. His carefully verified hypothesis become a piece in the puzzle that Vidya used to understand and explain the molecular mechanisms of genetic regulation.

In the GenEvo course, the agent-based restructurations of biological systems enabled students to develop a deep understanding of emergent ideas about genetic regulation and evolution. Traditionally they would have been told about these ideas authoritatively by their teachers using static models or animated videos to remember and then asked to explain those in the exams. Whereas in this course, students developed deep understanding of these ideas through ESM-mediated scientific inquiry. They collaboratively constructed knowledge about those ideas by asking questions, planning and carrying out investigations, analysing and interpreting evidence, and communicating their findings with others.

CONCLUSIONS AND IMPLICATIONS

ESMs and ESM-based curricula are design frameworks for learning environments to engage students in authentic scientific inquiry practices and learning about complex emergent systems phenomena. ESMs mediate students' expansive learning by providing them computational objects-to-collectively-think-with, in the context of a microworld. In the GenEvo course, students performed scientific investigations using these microworlds, shared their findings, argued about those, and developed a deep understanding about disciplinary ideas by engaging meaningfully in authentic scientific inquiry practices. Our analysis of ESM-mediated expansive learning revealed, how agent-based representations and constructionist design principles made ESM-based curricula effective for collaborative knowledge construction in a classroom setting.

ACKNOWLEDGEMENTS

The work regarding the development of computational models was made possible through the generous support from the National Science Foundation (grants CNS-1138461, CNS-1441041 and DRL-1020101) and the Spencer Foundation (Award #201600069). The authors gratefully acknowledge the support from partnering organisations, Center for Talent Development, Northwestern University and Educational Initiatives, India. The authors are especially grateful to Ragini Lalit, Sachin Vaishampayan, Anagh Purandare, Dr Aniruddh Sastry and Vishnuteerth Agnihotri for their support for the work in India.

REFERENCES

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching, 53(7),* 1082-1112.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education, 86(2),* 175-218.

Dabholkar, S. & Wilensky, U. (2016). GenEvo Systems Biology curriculum. http://ccl.northwestern.edu/curriculum/genevo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Dabholkar, S., Anton, G., & Wilensky, U. (2018) GenEvo - An emergent systems microworld for model-based scientific inquiry in the context of genetics and evolution. *Proceedings of the International Conference for the Learning Sciences*, London, UK.

Dabholkar, S. & Wilensky, U. (2019). Designing ESM-mediated collaborative activity systems for science learning. *Proceedings of International Conference of Computer Supported Collaborative Learning 2019*, Lyon, France.

Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of research in education, 32(1)*, 268-291.

Edwards, L. (1995). Microworlds as representations. In A. A. diSessa, C. Hoyles, & R. Noss (Eds.), *Computers and exploratory learning* (pp. 127–154). New York: Springer.

Engeström, Y. (2001). Expansive learning at work: Toward an activity theoretical reconceptualization. *Journal of education and work, 14(1)*, 133-156.

Glaser, B. G., & Strauss, A. L. (2017). *Discovery of grounded theory: Strategies for qualitative research*. Routledge.

Hmelo-Silver, C. E., & Azevedo, R. (2006). Understanding complex systems: Some core challenges. *The Journal of the learning sciences, 15(1)*, 53-61.Jacobson, M. J., & Wilensky, U. (2006). Complex systems in education: Scientific and educational importance and implications for the learning sciences. *The Journal of the learning sciences, 15(1)*, 11-34.

Kafai, Y. B., & Resnick, M. (2012). Introduction. *In Constructionism in practice* (pp. 13-20). Routledge.

Lehrer, R., & Schauble, L. (2006). *Cultivating model-based reasoning in science education*. Cambridge University Press.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic Books, Inc.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., & Duncan, R. G. (2004). A scaffolding design framework for software to support science inquiry, Journal of the Learning Sciences, 13, 337–386.

Schwarz, C. V., Passmore, C., & Reiser, B. J. (2017). *Helping students make sense of the world using next generation science and engineering practices*. NSTA Press.

Wagh, A., Cook Whitt, K., & Wilensky, U. (2017). Bridging inquiry based science and constructionism: Exploring the alignment between students tinkering with code of computational models and goals of inquiry.

Journal of Research in Science Teaching, 54(5), 615-641.

Wilensky, U., & Reisman, K. (2006). Thinking like a wolf, a sheep, or a firefly: Learning biology through constructing and testing computational theories—an embodied modeling approach. *Cognition and instruction, 24(2)*, 171-209.

Wilensky, U., & Resnick, M. (1999). Thinking in levels: A dynamic systems approach to making sense of the world. *Journal of Science Education and technology, 8(1)*, 3-19.

Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Yoon, S. A., Goh, S. E., & Park, M. (2018). Teaching and Learning About Complex Systems in K–12 Science Education: A Review of Empirical Studies 1995–2015. *Review of Educational Research, 88(2)*, 285-325.

SURVEY OF STUDENT UNDERSTANDING OF ELECTRIC FORCE AND FIELD

Santosh Kumar Umar*, Ashok Kumar Mittal and Vivek Kumar Tiwari
Physics Department, University of Allahabad, Prayagraj, U.P., India
santosh.91k@hotmail.com

The basic purpose of this study is to find whether students can identify and overcome their deficiencies in a narrow range of concepts through self-reflection, self-study and self-sought discussion, induced by a large number of practice question focused on the concepts. For this purpose, a narrow range of concepts pertaining to electric force and field were tested. The pre-test consisted of the ten conceptual multiple-choice questions pertaining to electric force and field in the well-known Conceptual Survey of Electricity and Magnetism (CSEM). After pre-test was administered, a large number of similar questions were sent to the students by e-mail and they were advised to ensure that they can answer such questions before a post-test to be administered within a few weeks. This survey covers more than 1000 Physics students at different levels of physics learning at different institutions.

INTRODUCTION

Physics is a concept-based subject. A central goal of Physics Education is to develop a proper conceptual understanding of students on different topics. Physics Education Research (PER) as a field of study emerged to provide reproducible and quantifiable conclusions related to conceptual understanding. It has created a large body of reliable knowledge to help improvement in physics instruction and techniques. Physics Education Researchers have developed several standardized concept-tests in different topics in Physics that have to satisfy stringent requirements of reliability and validity (Adams & Wieman, 2011; Engelhardt, 2009). These tests are administered before instruction and after instruction. The learning gains on such concept tests help compare the effectiveness of different instruction strategies. The standard definition of learning gain in PER is the ratio of 'increase in percentage score' and '(100 – percentage pre-score)' the latter being the maximum possible increase in the percentage score. PER studies have consistently demonstrated that interactive engagement techniques lead to significant gains in conceptual learning as compared to traditional lecture-based instruction (Hake, 1998) leading to the introduction of reformed Physics programs at several places (Crouch & Mazur, 2001). The Force Concept Inventory (FCI) (Hestenes, Wells & Swackhamer, 1992), Force and Motion Conceptual Evaluation (FMCE) (Thornton & Sokoloff, 1998), Brief Electricity and Magnetism Assessment (BEMA) (Chabay & Sherwood, 1997) and Conceptual Survey of Electricity and Magnetism (CSEM) (Maloney, O'Kuma, Hieggelke, & Van Heuvelen, 2001) are amongst the concept tests which have been widely used for investigating students' understanding. In most studies, the pre-tests are administered in the initial weeks of a semester course and post-tests towards the end of the semester. Concept tests such as BEMA and CSEM cover many sub-topics and concepts in Electricity and Magnetism. Such coarse-grained tools can help compare broadly the efficacy of different instruction strategies, but are not useful for identifying conceptual deficiencies in an individual student and for taking remedial action. For this purpose, it is necessary to administer fine-grained concept tests and reduce the time lag between pre- and post-tests. Here, the pre-test and the post-test mean tests administered before and after a remedial intervention. Accordingly, the ten questions in CSEM pertaining to electric force and field were taken as constituting a fine-grained pre-test. This subset (CSEFF = Conceptual Survey of Electric Force and Field) consists of ten multiple-choice questions (or items). One of the reasons, for choosing CSEM was that the performance on individual questions in pre- and post-tests in the CSEM are available for comparison with our survey, even though the meaning of pre- and post-test in CSEFF is different. The broader purpose of our studies is to quantify the impact of different types of remedial actions for overcoming conceptual deficiencies. In today's world it is easy to get information, therefore an important, perhaps the most important, learning goal is to develop the ability to answer questions through self-study, through self-sought discussion with peers and instructors, and through self-reflection. This ability is expected to improve with the advancement of learning stages. Unlike FCI, CSEM is a broad survey instrument. There cannot be a single concept inventory for such a broad range of topics. However, CSEFF, a sub-set of CSEM, can serve as a single concept inventory for Electric Force and Field, comparable to FCI. In the present study, after administering the pre-test, a large number of similar questions were sent to the students by e-mail and they were advised to ensure that they can answer such questions before a post-test to be administered within a few weeks. The pre-test, post-test and the set of intervention practice questions can be obtained by email. In this way, an attempt is made to evaluate the unsupervised self-learning skills that students have developed for answering a class of similar questions pertaining to a very narrow range of concepts. In addition, the survey was also carried out over participants in a refresher course for college and university teachers from all over India, held at the Physics Department, a leading Indian University. All the participants had Ph.D. degrees and varying lengths of teaching experience. They are well set on the path of Physics learning and teaching as a profession. Compared to students, they can be expected to have better self-learning skills and therefore better ability to overcome any deficiencies on the pre-test.

The following research questions are addressed in this study:

- How do statistical test characteristics of CSEFF compare with recommended values?
- How do the option choices for different items vary with the ability of students?
- To what extent does the unsupervised intervention of self-directed study, induced by several similar problems, help improve conceptual understanding of narrowly focussed concepts?
- What conceptual difficulties are indicated by CSEFF and how do they compare with those reported for CSEM?
- To what extent does the conceptual understanding of electrostatic force and field improve with learning stages from B.Sc. I Year to M.Sc. Final.

METHODOLOGY

The CSEFF was administered as a pre-test to students at various stages of physics learning from a B.Sc. First Year to M.Sc. Final Year and to participants of the refresher course, without any pre-announcement. The reason for not giving any advance notice was to evaluate the internalization of concepts and not memorization for a test. After the completion of the pre-test, a set of 57 problems were sent to the students by email. Twenty of the self-study questions (two for each item on the pre-test) were minor variants of the ten items on the pre-test, therefore presumably had the same difficulty level. The remaining were a mix of simpler and more complicated versions of the items on the pre-test. The answers were not given, as the purpose was to evaluate problem-driven self-learning skills. Students were advised to ensure that they can answer such questions before a post-test to be administered any time between one to four weeks. A post-test consisting of questions very similar to the pre-test was administered, again without announcing the exact date of such test. Each item in the post-test was a minor variant of the corresponding item in the pre-test, allowing the computation of item-wise learning gains.

DATA ANALYSIS

Table 1 shows the percentage of students who chose different options for each item on CSEFF. Table 2 shows item-wise percentage correct response on pre-test and post-test. It also shows the learning gains for each item. Table 3 shows the item-wise correct response at different stages of learning. It also includes a column of the reported response in the pre-test given to introductory students in US universities.

Item		N	A (%)	B (%)	C (%)	D (%)	E (%)
1	Pre-test	1070	4	**67**	15	13	1
	Post-test	770	11	14	**69**	5	1
2	Pre-test	1063	9	**58**	13	19	1
	Post-test	768	18	14	**60**	8	0
3	Pre-test	1050	15	7	**58**	15	6
	Post-test	758	23	17	11	**42**	7
4	Pre-test	1062	14	23	18	15	**28**
	Post-test	767	10	17	**53**	8	11
5	Pre-test	1044	28	**21**	23	16	12
	Post-test	754	26	**33**	23	11	6
6	Pre-test	1049	8	**28**	21	26	17
	Post-test	762	12	25	24	**31**	8
7	Pre-test	1051	8	**28**	24	28	11
	Post-test	758	11	17	35	**21**	15
8	Pre-test	1047	11	33	**22**	13	21
	Post-test	750	22	**26**	26	19	8
9	Pre-test	1053	12	13	15	**47**	13
	Post-test	759	12	15	16	**46**	10
10	Pre-test	1061	22	23	**25**	15	15
	Post-test	763	22	26	**27**	14	11

Item	Topic	CSEFF Pre N ~ 1000	CSEFF Post N ~ 1000	Learning gain = (post – pre)/ (100 – pre)
1	Coulomb's law	67	69	0.061
2	Coulomb's law	58	60	0.048
3	Coulomb's law	58	42	-0.38
4	Coulomb's law + Principle of superposition	28	53	0.35
5	Coulomb's law	21	33	0.15
6	Coulomb's law + Principle of superposition	28	31	0.042
7	Coulomb's law + Principle of superposition	28	21	-0.097
8	Electric field + Newton's law	22	26	0.051
9	Electric lines of force	47	46	-0.019
10	Electric Lines of Force	25	27	0.027
	Average	**38**	**41**	**0.048**

Table 1: Percentage of student chosing different option, **Table 2:** Learning gain

Item	Topic	US Pre N~1000	B.Sc. I N = 434	B.Sc. II N = 290	B.Sc. III N = 134	M.Sc. Previous N = 95	M.Sc. Final N = 55	Refresher Course Teacher Participants N = 26
1	Coulomb's law	74	64	76	71	73	82	65
2	Coulomb's law	44	53	55	72	63	71	46
3	Coulomb's law	39	31	57	60	61	71	50
4	Coulomb's law + Principle of superposition	61	48	32	29	29	40	38
5	Coulomb's law	25	26	20	24	24	25	35
6	Coulomb's law + Principle of superposition	51	26	27	37	29	25	38
7	Coulomb's law + Principle of superposition	48	21	25	31	29	35	42
8	Electric field + Newton's law	24	21	18	22	22	35	23
9	Electric lines of force	60	37	44	49	62	58	69
10	Electric Lines of Force	17	23	24	24	21	24	31
	Average	44	**35**	**38**	**42**	**41**	**47**	**44**

Table 3: Item wise correct response at different stages of learning

Statistical characteristics

Some of the statistical characteristics (Ding, Chabay, Sherwood & Beichner, 2006), that are often used in PER for ensuring their reliability and validity are item difficulty index, item discrimination index, point-biserial index, KR-21 reliability index, Ferguson delta. It is necessary to evaluate these characteristics for the CSEFF as they depend also on the student population.

Difficulty index of an item: The difficulty index of an item in the test is defined by;

$$P = N_1/N \qquad (1)$$

Here N is total number of students and N_1 is the number of students choosing the correct option, thereby scoring 1 for the item. The difficulty index for different items of CSEFF is shown in Fig 1(a). None of the items has difficulty index less than 0.2 or more than 0.7. The average difficulty index for the whole test is 0.38.

Discrimination index of an item: The discrimination index of an item gives information about the contribution of the item for discriminating between high scoring (> 75 percentile) and low scoring (< 25 percentile) students on the entire test. It is defined by

$$D = 4(N_{H-} - N_L)/N \qquad (2)$$

where N_H and N_L are the number of correct responses to the item by the high scoring and low scoring groups respectively. According to classical test theory, items (e.g. 1, 2 and 3) with difficulty index around 0.5 are likely to have high discrimination index and items with difficulty index away from 0.5 (whether on the high side or the low side) are likely to have low discrimination index. Fig.1(b) shows the discrimination index for different items of CSEFF. The average value of the discrimination index is 0.48. An item is considered to have satisfactory discrimination if the discrimination index is greater than 0.4. Only items 8 and 10 failed this condition.

Point Biserial reliability Index: The point biserial index, a measure of the consistency of one item with the whole test, is defined by the correlation between the item score and the total score. It is given by

$$r_{pbs} - \frac{\bar{X}_1 + \bar{X}}{\sigma x}\sqrt{\frac{P}{1-P}} \qquad (3)$$

where $\bar{X}_1$ is the total score average for the students who answered the item correctly, $\bar{x}$ is the total score average for the whole test, σx is the standard deviation for the whole test and P is the difficulty index. Fig.1(c) shows the point biserial coefficient for each item of CSEFF. An item is considered good if its point biserial is > 0.25 and the recommended average value is ≥ 0.2. For CSEFF, all items had point biserial > 0.3 with an average of 0.4.

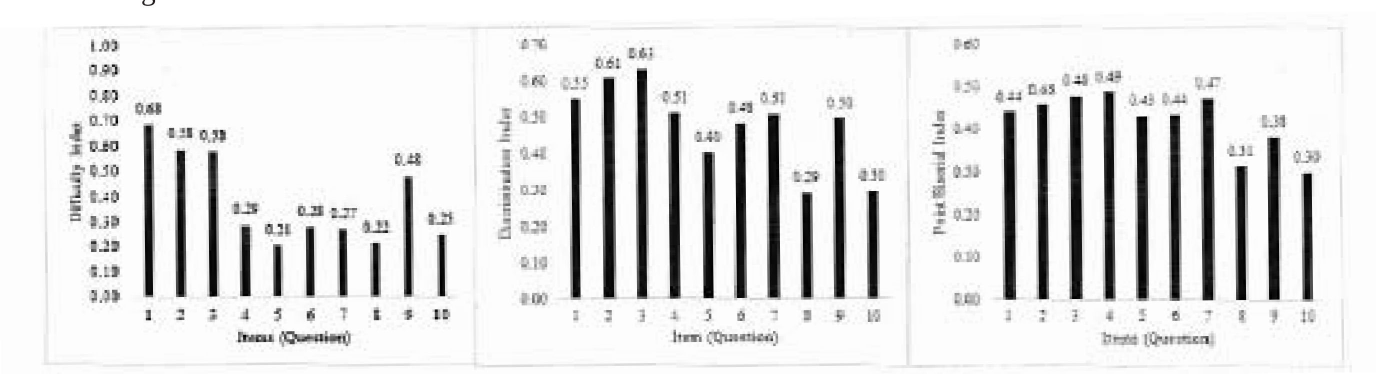


Figure 1: (a) Difficulty index, **Figure 1(b):** Discrimination index, & **Figure 1(c):** Point Biserial index

KR-21 test reliability index for the whole test: The Kuder Richardson reliability index measures the self-consistency of the whole test. KR-21 reliability index is the average correlation between all possible divisions into two parts, each having half the number of items. For a dichotomous multiple-choice test, it is given by

$$r_{test} = \frac{K}{K-1}\left(1 - \frac{\sum P(1-P)}{\sigma_X^2}\right) \qquad (4)$$

Here K is the total number of test items in the whole test, P is difficulty index and σx is the standard deviation of the total score. The recommended value for a good test is $r_{test} \geq 0.8$. For CSEFF the value of is 0.98.

Ferguson delta for the whole test: Ferguson Delta is a measure of the discriminatory power of the whole test. Let, be the number of students whose total score is i. Ferguson's delta is defined by;

$$\delta = \frac{K+1}{K}\left\{1-\sum_{i=0}^{R}\left(\frac{f_i}{N}\right)^2\right\} = \frac{N^2 - \sum_i^k =_0 f_1^2}{N^2 - \frac{N^2}{K+1}} \tag{5}$$

For a good test, it is recommended that Ferguson delta should be > 0.9. The value of Ferguson's delta for CSEFF is 0.93.

Item response curves

Table I shows item-wise percentage responses to different options both for the pre-test and post-test. The correct option is shown in bold. This table gives the overall performance of all students without distinguishing between the varying abilities of students. The total score on the test may be taken as a measure of the ability of students. The response data is separated for students of varying ability as indicated by the total score. A table, like Table I, is prepared separately for each value of the total score. The data for all such tables is represented in the form of Item Response Curves (IRC) (Morris et al., 2006; Morris et al., 2012) as shown in Fig 2(a) for pre-tests and 2(b) for post-tests. As expected, with increasing ability the IRC's show an increasing trend for the correct option and a decreasing trend for the wrong options. For low scoring items like 5, 7, 8 and 10, the IRC's of the correct options start from 0 and rise steeply only at mid or high ability levels. For high scoring items like 1, 2 and 3, they start at relatively high values and rise slowly to flatten out as mid and high ability students have a high probability of answering them correctly.

Impact of interventional questions

The extent to which unsupervised intervention of self-directed study, induced by several similar problems, helped improve conceptual understanding of electrostatic force and field is shown in Table II. The average learning gain is a modest 0.048. Most of the items showed very little change. Item 4 was the only item that showed substantial learning gain. There was a substantial decrease in the correct option for item 3 and an increase in the wrong option (a). In the post-test, the distance was decreased, instead of increasing. It seems that several students still have problems in dividing by a fraction, causing a substantial increase in option (a). In figure 2(c) we show for each item, the correct option IRC's for pre- and post-tests juxtaposed together. Item 7 in figure 2(c) reveals a surprising and inexplicable feature: low ability students show improvement in the post-test, whereas high ability students show a decline.

Identification of misconception

As in CSEM, item1 was the easiest item in CSEFF for students of different abilities and at different learning stages in pre-tests as well as post-tests. Analysis of distractor responses to this item throw some surprising insight about possible misconceptions. About 15% answered that the force on a charge remains unchanged if the magnitude of the other charge is increased by a factor of 4. About an equal number answered that the force will decrease by a factor of 4. These answers are far more frequent than the other wrong options for no apparent reason. This trend is seen for items 1 and 2 in the pre-tests as well as the post-tests. This suggests that the wrong options are the consequence of misconceptions rather than random choices.

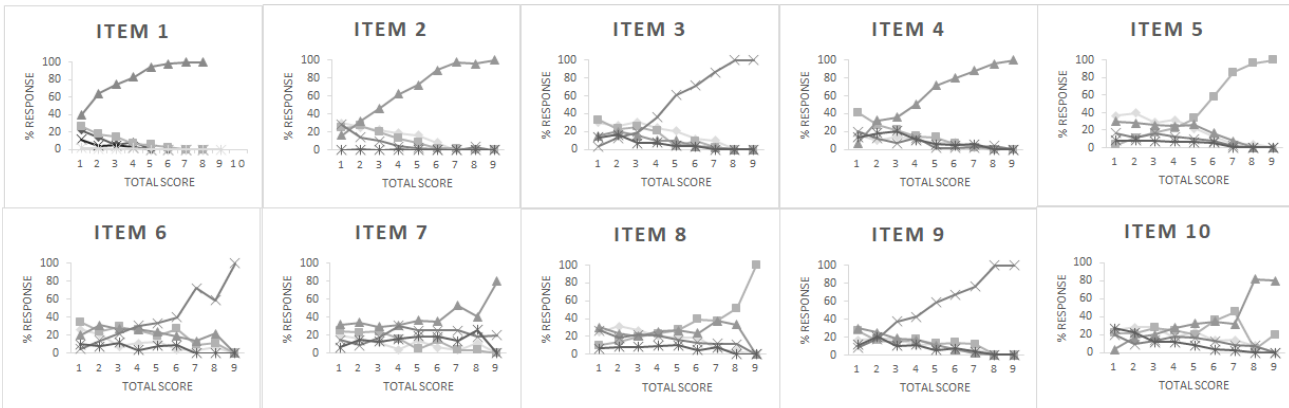


Figure 2(b) Post-test IRC's [✧ is option (a), □is option (b), Δ is option (c),x is option (d) and * is option (e)]

Figure 2(c) [◇for pre-test and □ for post-test]

In CSEM, the number of correct responses to item 2 were about 33% less than to item 1, although from an expert perspective, the two items are almost identical. Commenting on this result, it was remarked in (Maloney, *et al.*, 2001) that many students do not apply Newton's Third Law or symmetry of Coulomb's Law, that students seemed to believe that larger objects (in this case larger charges) exert larger forces than smaller objects. In CSEFF, the number of correct responses to item 2 were only about 14% less than to item 1. Responses to items 1, 2 and 5 do not support the view that students believe that greater charges exert greater forces. The distribution of wrong responses in CSEM is very different from those for CSEFF. Item 3 tests the understanding of distance dependence of electrostatic force between two charges. The problem with this item is that it is not independent of item 2. Those who get answer to item 2 wrong due to some misconception, cannot answer item 3 correctly. In CSEM, the number of persons who answered item 3 correctly was slightly less than those who answered item 2 correctly, suggesting that some students have problems with the inverse square dependence of the Coulomb's Law. In the CSEFF pre-test, however, both items 2 and 3 were answered correctly by the same percentage of students, suggesting that they do not have problems with the inverse square dependence.

In CSEFF, item 4 was answered correctly by only 28% students in the pre-test and 53% students in the post-test. This was the only item with substantial learning gain. From an expert perspective, items 6 and 7 are the most difficult in CSEFF, as they involve relatively lengthy problem description, intermediate stage inference and reasoning skills. These items were correctly answered by 28% students only, substantially less than CSEM students.

Items 8 and 10 were the most difficult in our survey, with difficulty index less than 0.25. Table III shows that in the reported CSEM studies also, pre-test scores on items 8 and 10 had difficulty index less than 0.25. As in CSEM, the number of students in CSEFF who answered item 8 correctly was much less than those who answered item 9 correctly, suggesting that many students still thought that application of constant force on a body would give rise to constant velocity.

CONCLUSION

CSEFF is a reasonable fine-grained instrument for assessment of conceptual understanding of electric force and field, which satisfies the statistical parameters recommended for concept tests. Item Response curves (Figure 2) provide graphs of how student performance on different options vary with ability. These graphs are easy to interpret and provide useful insight. The average learning gain due to self-learning questions was a modest 0.048. Only item 4 showed substantial learning gain. This could be because the correct option in the pre-test was 'none of these' which students tend to avoid. As argued in subsection III, substantial negative learning gain for item 3 could be due to students having problem in dividing by a fraction. Inexplicably, the performance of low ability students on item 7 improved in the post-test, whereas that of high ability students deteriorated. A serious limitation of our study is that it relies wholly on intrinsic motivation for students to try and do well in the post-test. In future studies we plan to introduce some extrinsic motivations so that students work on the intervention problems more seriously towards better performance on the post-test. It seems that a large number of students have problems with the principle of superposition and/or vector addition. A finer grained survey will be conducted for understanding the detailed nature of the misconceptions related to the principle of superposition as a follow-up of the present survey. Compared to CSEM, performance of CSEFF students was substantially poorer on problems involving lengthy description, intermediate stage inference and reasoning skill. Overall performance of students in CSEFF was found to increase slightly with advancement of learning stages from BSc I year to M. Sc. Final. The table shows a significant improvement only at the M.Sc. Final stage. This shows that students do not improve their understanding of electrostatic force and field with advancement of learning stages. Improvement at the final year stage could be because students start preparing for entrance tests for research programs, which test understanding of basic physics concepts better than the more memory-based tests in their regular courses. However, the performance of teacher participants in the Refresher Course was very disappointing and should be a cause of concern for Physics Education in India. Inferences drawn from CSEFF are suggestive and require carefully planned studies for confirmation.

ACKNOWLEDGEMENTS

Authors are thankful to the Physics Department, University of Allahabad and its affiliated Colleges for giving us the opportunity to carry out the survey. One of the author SKU is thankful to UGC, New Delhi for providing him financial assistance.

REFERENCES

Adams, W. K., & Wieman, C. E. (2011). Development and validation of instruments to measure learning of expert like thinking. *International Journal of Science Education*, *33*(9), 1289-1312.

Chabay, R., & Sherwood, B. (1997). Qualitative understanding and retention. *AAPT Announcer*, *27*(2), 96.

Ding, L., Chabay, R., Sherwood, B., & Beichner, R. (2006). Evaluating an electricity and magnetism assessment tool: Brief electricity and magnetism assessment. *Physical review special Topics-Physics education research*, *2*(1), 010105.

Engelhardt, P. V. (2009). An Introduction to Classical Test Theory as Applied to Conceptual Multiple-choice Tests in Getting Started in PER, edited by C. Henderson and KA Harper, American Association of Physics Teachers, College Park. *MD Reviews in PER*, *2*.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American journal of Physics*, *66*(1), 64-74.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The physics teacher*, *30*(3), 141-158.

Maloney, D. P., O'Kuma, T. L., Hieggelke, C. J., & Van Heuvelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. *American Journal of Physics*, *69*(S1), S12-S23.

Morris, G. A., Branum-Martin, L., Harshman, N., Baker, S. D., Mazur, E., Dutta, S., ... & McCauley, V. (2006). Testing the test: Item response curves and test quality. *American Journal of Physics*, *74*(5), 449-453.

Morris, G. A., Harshman, N., Branum-Martin, L., Mazur, E., Mzoughi, T., & Baker, S. D. (2012). An item response curves analysis of the Force Concept Inventory. *American Journal of Physics*, *80*(9), 825-831.

Thornton, R. K., & Sokoloff, D. R. (1998). Assessing student learning of Newton's laws: The force and motion conceptual evaluation and the evaluation of active learning laboratory and lecture curricula. *american Journal of Physics*, *66*(4), 338-352.

UNDERGRADUATE STUDENTS' MENTAL MODELS OF ELECTROSTATIC POTENTIAL

Mahima Chhabra[1] and Ritwick Das[2]
University of Delhi, India[1], National Institute of Science Education and Research, India[2]
mahima.chhabra@gmail.com, ritwick.das@niser.ac.in

Electromagnetism (EM) is considered as one of the essential components of core physics course where 'Electrostatics' lies at its foundation. 'Electrostatic Potential' is one of the most crucial concepts introduced in electrostatics connecting most fundamental physical quantities namely, electrostatic field and potential energy. Therefore, clarity in understanding of electrostatic potential is crucial for interaction of charges (or charge distributions) with an electric field. Since it is presented at undergraduate level in a highly mathematical and abstract framework, there remains scope for development of students' mental model which are divergent from the well-negotiated scientific concepts. Therefore, in this study, we have made an attempt to explore students' mental models for the concept of 'Electrostatic Potential by using problem solving tasks and interviews. We have found significant alternative conceptions which pose a challenge for meaningful learning.

INTRODUCTION

Electromagnetism (EM) is amongst the core subjects in undergraduate physics curriculum and plays a pivotal role in the development of many applied as well as interdisciplinary areas in physics. At the undergraduate (UG) level, EM is introduced conceptually with electrostatics in a highly abstract and mathematical framework (Griffiths, 2013). Electrostatics is substantially less intuitive than classical mechanics (which is introduced first at the UG level) and therefore, in addition to the common sources of misconceptions borrowed from mechanics, there is a variety of sources which are related to the abstract new concepts of electrostatics (as well as magnetostatics). In fact, conceptual development of electrostatics through experiments at an undergraduate level is a rare occurrence (Dvořák, 2012). There are a very few 'classroom environment' experiments in electrostatics through which, quantifiable information could be derived (Dvořák, 2012; Liengme, 2014). Hence, the basis of certain assumptions as well as 'laws' in electrostatics could be interpreted by students in varied manner when the concepts are introduced to them. In addition, the complex nature of mathematically defined quantities (including vectors, complex numbers, derivatives etc.) in electrostatics results in unforeseen cross-linkages in conceptual framework and consequently, students may have varied mental models at the undergraduate level. Within the constructivist framework those mental models which are divergent from well negotiated scientific concepts of the given time can be referred to as alternative conceptions (AC). Such AC in the area of electrostatic force/field and current electricity have been investigated by a few groups across the globe, essentially from an application perspective (Bull, Jackson & Lancaster 2012; Aubrecht & Raduta, 2005; Baybars, 2019; Samsudin et al., 2019). In one of the recent studies, Lindsay

(2014) presented an exploratory investigation on UG students' conceptions about electrostatic and gravitational potential energy which is crucial for making sense of energy (potential) in chemistry as well as biology.
In electrostatics, potential energy in charged systems is essentially derived from basic understanding of electrostatic potential and field. In fact, electrostatic potential (scalar) is one of the most-used physical quantities in electrostatics as it connects all the three spatial components of electric field vector on one hand and electrostatic potential energy on the other. Due to the fact that the formal definition of electrostatic potential (V) entails unavoidable mathematical and abstract formalism, the physical picture of the concept of potential amongst UG students may be varied and therefore, the possibility of development of divergent mental models is high. Thus in the present work, we have investigated the mental models of the concept of electrostatic potential of a group of UG students majoring in physics.

RESEARCH QUESTIONS

- Does students face difficulty in understanding the concept of 'potential' in electrostatics? If yes, what could they possibly be.
- Do they consider that the presence of an electrostatic field results in existence of potential?
- Is it likely that they borrow idea from other concepts (such as potential energy, electric field) to associate a meaning to electrostatic potential?
- Is their mathematical understanding of 'potential' coherent with physical concept of potential?

METHODOLOGY

This research focuses on patterns of errors learners commit while solving the problems based on relationship between electrostatic field and electrostatic potential in the case of uniform electric field. The aim is further to explore if these errors are simple mistakes or do they have roots in students' conceptions of the scientific concept. Thus this study is situated in the qualitative paradigm where objective is to unravel the students' mental models of the concept as they solve problems. To this end we have selected three relevant questions from a standardized tool BEMA (Ding,Chabay,Sherwood & Beichner, 2006) . These questions were administered to the participants as a Quiz before the concept of 'electrostatic potential' was taught in the class. The questions were objective type with choices (a to g). For our purpose we had added another choice 'h' (any other). Students were required to choose the correct option in their view and also provide an explanation for their choice. Also after the Quiz each student was interviewed in detail about their responses and explanations. After the topic was done in the class another Quiz was administered with two multiple choice objective type questions. These questions were constructed by us and have 5 options (a-e) in which option 'any other' is included (Appendix). Again students were required to provide a correct choice followed by written justification for their choice and subsequently interviews regarding their explanations and choices were conducted.

The analysis has been done within the paradigm of constructivism with the basic assumption that each student constructs his/her own knowledge. The written responses and interview data was analysed together and some significant errors which were repeated by learners and had roots in students' conceptual understanding have been referred to as students' alternative conceptions and presented in the next section .

Participants for this research were a class of 18, 1st-year UG students of physics, studying at National Institute of Science Education and Research (NISER) situated in Odisha , India. The tests were conducted during the course on Electricity and Magnetism (EM). This is the first course of EM for students at undergraduate level, thus their prior conceptions about Electrostatics are those which they carried from their school level. Also, they have credited a course on classical mechanics prior to this course on EM.

RESULTS

The selected questions from BEMA are referred to here as Q1, Q2 and Q3. They are based on a situation where a uniform electric field is given in a plane and 4 points are considered. Students are required to find the potential difference between two points situated along the electric field in Q1, two points situated perpendicular to electric field in Q2 and two points which are diagonal to electric field in Q3. Options 'a', 'b','c' and 'd' of the MCQ indicate the potential difference between two given points as product of electric field and shortest distance between the given points with negative and positive signs . Choices 'e' and 'f' indicate the potential difference to be path dependent showing it to be the product of electric field and actual distance travelled to reach final point from initial point . Choice 'g' indicates the potential difference to be zero and another choice 'h' added by us indicates 'none of the above'. Other two questions constructed by the researchers are referred to as Q4 and Q5 and are given in Appendix. Students' choices are presented in table 1 given below. Students are referred to as S1, S2, S3…..S18 in the text.

Choices ---------- Question	a	b	c	d	e	f	g	h	Not Answered
Q1	S6,S14	S1,S2,S3,S4, S7,S8,S9,S10, S11,S12,S13,S15S16,S17,S18							S5
Q2							S1,S2,S3,S4, S6,S7, S8,S9,S10,S11, S12,S13,S14,S15, S16,S17,S18		S5
Q3	S6,S14	S1,S3,S7,S8,S9,S10,S11,S12, S13S15,S16,S17,S18				S2,S4			S5
Q4	S1,S2, S3, S5, S6, S7, S8, S9, S10, S11, S12, S13, S15, S16, S17, S18					-	-	-	S4,S14
Q5	S1, S3, S5, S6, S7, S11, S15, S17, S18			S8,S9, S10,S12, S13,S16		-	-	-	S2,S4,S14

Table 1: Students' Responses

We have observed the following alternative conceptions in the study.

E1: Potential is a vector

The concept of potential was specifically devised in electrostatics for the purpose of simplifying the complex vector calculations. It is negative gradient of electric field and thus a scalar quantity. While teaching, it is generally the third significant concept presented in the class after force and field. An important point to note is that force as well as field is a vector quantity. It was observed that many learners carried a strong alternative conception that potential was a vector. One of the reasons could be extrapolation of the properties of force and field which were presented prior in sequence to potential. This alternative conception was shown in many ways by learners specifically in Q1, Q2 and Q3. S2 directly expressed his belief in the interview that potential is a vector quantity. Further he could state the mathematical formula for potential to be a dot product between $\vec{E}$ and $d\vec{l}$, but he did not seem to understand the meaning of dot product as well (which is a multiplication between two vectors resulting in a scalar). On the other hand S17 depicted potential with a vector sign ($\overrightarrow{V}$) while solving the task in written form. He also depicted the relation between potential at two points in Q1 as $|V_1| > |V_2|$. Now, since the potential is a scalar quantity, the use of modulus does not hold any significant meaning here. While answering Q2, S17 mentioned "*potential is perpendicular to electric field*" i.e. he expressed potential in terms of a particular direction. It indicates that the learner extrapolated his conceptions of vectors to potential as well.

E2: Potential has an absolute value

Potential is defined with respect to a *conveniently* chosen reference, therefore we always measure potential difference instead of 'absolute potential'. While answering Q1, S17 wrote "*let* V1 = -Ew; V2 = -E +) = 0; V_2 -V_1 = –Ew; $|V_1| > |V_2|$ *which implies* $V_2 > V_1 = -ve$". Here, he equated potential at point 1 to '–Ew' which was incorrect since '–Ew' is the potential difference between point 1 and 2 rather than an absolute value at point 2. Also, it showed that he did not view potential to be a line integral of electric field over a path from one point to another. Instead, he understood potential to be having absolute values at various points in space which showed a clear alternative conception in his metal model.

Another manifestation of considering potential to have an absolute value was evident when S2 while answering Q4 marked the correct option but explained the reason in the following manner:

$$"V = -\int_a^b \vec{E}.d\vec{l} = -\int_a^b Ex.d\vec{l}\ , x, y = 0; \cos 90^\circ = 0;$$

At B and D V=0"; Since, points B and D were located on an equipotential surface thus, the potential difference between them was zero and not the value of potential itself.

E3: Only magnitude of field is important to calculate potential

Electric field is a vector quantity which comprises of both – magnitude and direction. While calculating potential difference between two points, dot product of field with distance between those two points is considered. It is important to note that the dot product involves only vectors and results in a scalar. Also, direction of both the vectors involved plays a crucial role while calculating dot product. Some learners were observed to believe that since potential is a scalar therefore to calculate potential only magnitude of field is important and the direction could be ignored which is an alternative conception. As a manifestation of this erroneous conception, S11 expressed in the first interview, that potential difference between any two points should be zero when magnitude of electric field is the same. She further added that these two points could be inferred to be on an equipotential plane, which is an incorrect inference.

E4: Negative sign in potential

Potential at a point P is defined as the negative integral of electric field with respect to distance i.e. . This negative sign depicts that the 'work', in bringing a test charge from infinity to point P, is done against the existing field due to some charges already present in the system. Thus, there is a physical reason for the negative sign being present in the equation. It was observed that students frequently missed this negative sign while calculating potential. Some learners were also observed to use it at their convenience, i.e. they used it in some questions and did not use it in other questions. Within the same task, S1 used it in one step and missed it in the other. Another student was observed to use a positive sign throughout the solution but brought a negative sign in the last step without stating any logic for inserting it. Due to the inconsistent use of the negative sign, at times learners were also observed to reach incorrect answers. For instance S6 got both his answers of Q1 and Q3 incorrect as he did not find any importance of negative sign in calculating potential. S2 although marked correct option as an answer to Q1, however while explaining in the interview he changed his answer to option 'a' explicitly mentioning that "*negative sign is only for indicating work done and not significant in calculating potential*". It shows that these learners lacked understanding of physical meaning of the concept as well as self-consistent mathematical framework to arrive at physically acceptable results.

E5: Limits of integration

Within a discipline, conventions are defined to make communication easier and less ambiguous. It helps everyone understand the same meaning of the given relation. In the case of integration, limits '*a*' and '*b*' are shown as $\int_a^b f(x)\,dx$ where '*a*' is the lower limit and '*b*' is the upper limit. Physically it means '*a*' is the initial point and '*b*' is the final point. While solving the integral the final relation is calculated as:

$$\int_a^b f(x)\,dx = [g(x)]_a^b = g(b) - g(a)$$

Learners were observed to show many errors regarding limits. Some learners (S1,S2,S4,S6) did not pay heed to the order of the limits (i.e. lower and upper) and calculated

$$\int_a^b f(x)\,dx = [g(x)]_a^b = g(a) - g(b)$$

Learners were observed to show many errors regarding limits. Some learners (S1,S2,S4,S6) did not pay heed to the order of the limits (i.e. lower and upper) and calculated

This interchange of limits changes the result by a negative sign which learners do not mention, resulting in incorrect answers, for instance Q1 and Q3 of S14. For some learners like S6 the order of limits did not matter while explaining the concept physically, he explicitly mentioned it in the interview. They interchangeably used the limits which showed that in their mental model the significance of order of limits as well as physical implications of a 'negative' sign in mathematical result was not important. Many of them felt that changing the sign would not make any difference because magnitude still remains the same. Whereas in the context of potential a positive or a negative sign represents whether work is done by the system or on the system which depict two independent and different cases. Another error noticed frequently was not mentioning the limits at all. Potential is a quantity which has a meaning only with respect to a reference point or in other words when a charge is moved over a distance (represented by dl) in the presence of electric field, only under that condition potential is defined. Hence understanding and mentioning the limits are very important while using potential.

E6: Potential is path dependent- Potential is derived from electric field using one of the most important properties of electric field i.e. conservative nature of field. It means curl of the electric field is zero i.e. it is irrotational. In other words, since curl of field is zero it can be expressed as a gradient of a scalar quantity which is defined as potential (V) in electrostatics. It also means that line integral of electric field is path independent or depends only on the end points. Therefore, in the relation

$$V(b) - V(a) = -\int_a^b \vec{E} \, . \, \vec{dl}$$

dl can be chosen to be any arbitrary path from *a* to *b*. That is, for each different path chosen *V(b) - V(a)* will remain the same, because it only depends upon the end points and not on the path. Some students tend to overlook this basic property while solving tasks. S4 marked correct option for Q1 and Q2 , however for Q3 he marked option 'f' which was incorrect. In the explanation to his choice, he substituted the value of dl to be $\sqrt{h^2 + w^2}$, which was the length of shortest 'distance' between point 1 and point 4. He perhaps could not appreciate the path independent nature of potential difference, due to which he could not combine the inferences from his answers in item no. Q1 and Q2. S2 on the other hand had chosen option 'f' for Q3 however in the interview he changed his option to 'a' (as he did for Q1).

E7: Field same means potential same- It was a common observation that students interchangeably used the names of the concepts e.g. field for potential or force for field. One of the manifestations of this error is seen when they extrapolate the properties of one concept into another concept. In response to Q2, the reason cited by S6 for his answer was *"since E is same for both points and that is why V should also be same"* or in other words 'if electric field at any two points is same then potential difference between those two points is zero' is an alternative conception. There could be conditions contradictory to this, such as given in Q1, where E is same for points 1 and 2 but still potential was different. In another instance, a student assumed that the 'electric field is constant' on equipotential surfaces, i.e. when potential is same field should be same indicating the alternative conception held by him.

E8: Gradient: Mathematical definition and physical understanding- 'Gradient' (of a scalar) is a mathematical operation which is used for determining the direction and magnitude of maximum change of a scalar. In order to mathematically estimate the 'gradient', the functional form of scalar function (whose gradient needs to be evaluated) should be necessarily known. However, if the scalar function is a constant over a surface, then it is expected that the 'maximum change' in that function will be along the direction perpendicular to the surface. In other words, the direction of the gradient of the scalar function will be along the direction perpendicular to the surface. Using this result, it is straightforward to show that the gradient of electrostatic potential will always be in a direction which is perpendicular to the equipotential surface. Many of the learners as shown in table 1 above could not ascertain this point and hence, they chose option d:'lack of information' in Q5. For instance, S10 mentioned *"there cannot be any electric field along the Y and Z direction anyway due to symmetry. To know the electric field, one needs to know V as a function of r, knowing it on a single plane is not sufficient"*. Although it is correct that one needs to electric electric field at two planes but the direction of electric field (negative of the gradient of potential) could be ascertained from the location of one equipotential surface as well. He missed this point which shows that he knows the mathematical aspects of a gradient of a scalar quantity but cannot connect it to a physical situation always.

DISCUSSION AND CONCLUSION

In the section above, following alternative conceptions have been observed: a) Potential is a vector b) Potential has an absolute value b) Only magnitude of field is important to calculate potential d) Negative sign in potential e) Limits f) Potential is path dependent g) Identical field amplitude implies identical potential (alternately, uniform electric in a region implies constant potential). Such an observations is made on the basis of repeated patterns which students exhibited in multiple situations during the interaction.

It is evident from the results that students' correct answer may not always project the real conceptual understanding as most students marked correct options for the given tasks. Their written explanations and oral interview gave us an insight into how they thought about the concept and how they linked one concept to another. It was observed a few times that the students wrote correct formulae however while using them to solve a problem, they got confused. The response of S6 in **E5** is a case in hand where the limits written by him (in written response) does not carry significant meaning. At times they could not substitute the variables in the formulae with the correct values given in the problem. A similar case is represented by S1 in **E4**. Incidents such as neglecting negative sign while calculating potential (S1 in **E4**), using incorrect order of limits or ignoring them altogether, not being able to utilise the concept of gradient to find direction of electric field (S10 in **E8**) shows a clear missing link between the mathematical representation and physical representation of the concept in their mental models. Further, aspects like interchangeably using the terms'field' and 'potential' at times (S6 in **E7**) not only shows naive error, it also reveals that the concepts are not delineated in students' mental models which, at times, result in one-to-one mapping of one concept to another. This issue may give rise to alternative conceptions such as considering potential as a vector (S2 and S17 in **E1**) and considering potential to be same at two points if electric field is uniform (S3 and S4 in **E6**). It, therefore, indicates a decent room for improvement in our teaching-learning classroom techniques in this topic which is accepted to be quite abstract. Possibly, after introducing the concept of 'potential' in formal manner, the students could be subjected to solve a variety of mathematical problems which require visualisation of concepts. For example, a question on estimation of ‘field’ and ‘potential’ for a symmetric charge distribution may be followed by tracing/drawing the equipotential surface. A well-designed mixed bag of questions related to one or related concepts may bring out inconsistencies in conceptual framework and subsequently rectify it as well. At times, a teacher needs to approach a problem in an unconventional (non-trivial) direction. Such reverse approach tends to create disequilibrium in case misconception/alternate conception exists. For example, estimation of a possible charge distribution from a pictorial representation of an equipotential surface could bring out inconsistencies in understanding of the relation between equipotential surface and electric field. However, this necessarily needs to be complemented with honest acknowledgement and analysis of the error. Eventually, such alternative conceptions must find an appropriate space in classroom discussions. Such an approach could help learners reflect on their concepts and find the points of divergence between what they understood and the widely accepted (well-negotiated) scientific concepts of the given time, further encouraging them to construct viable concepts.

REFERENCES

Aubrecht,G. J. & Raduta,C. (2005). Contrasts in Student Understanding of Simple E&M Questions in Two Countries. *AIP Conference Proceedings. 790.* pp. 85

Baybars,M. G.(2019). Determination of The Opinions and Alternative Concepts of Pre-Service Science Teachers About The Functions of The Elements of A Simple Electric Circuit..*European Journal of Physics Education, 10,* 1309-7202

Bull,S., Jackson,T. J., & Lancaster,M. J. (2012). Students’ Interest in Their Misconceptions in First-Year Electrical Circuits and Mathematics Courses. *The International Journal of Electrical Engineering & Education, 47(3),* 307-318 .

Ding, L., Chabay, R., Sherwood, B., & Beichner, R. (2006). Evaluating an electricity and magnetism assessment tool: Brief electricity and magnetism assessment. *Physical Review Special Topics - Physics Education Research, 2(1),* 010105.

Dvoøák, L.(2012).Low-cost electrostatic experiments. *Latin American Journal of Physics Education, 6,* 153-158.

Griffiths, D. J. (2013). *Introduction to Electrodynamics 4th Edition,* USA :Pearson Edu .

Lindsey,B. A. (2014).Student reasoning about electrostatic and gravitational potential energy:An exploratory study with interdisciplinary consequences.*Physical Review Special Topics-Physics Education Research,10,* 013101

Liengme,B. V. (2014).Electrostatics.In *Modelling Physics with Microsoft Excel* (pp. 10-1:10-6). Morgan and Claypool, USA .

Samsudin,A et al. (2019). Optimizing Students’ Conceptual Understanding on Electricity and Magnetism through Cognitive Conflict-Based Multimode Teaching (CC-BMT). *Journal of Physics: Conference Series, 1204,* 012027

LEARNING BASIC ASTRONOMY THROUGH AN EMBODIED AND INTERACTIVE APPROACH

Rafikh Shaikh[1], Shamin Padalkar[2], Glenda Stump[3], Prayas Sutar[4] and Arunachal Kumar[5]
Tata Institute of Social Sciences, Mumbai[1,2,4,5],
Massachusetts Institute of Technology, MA[3]
rafikh.shaikh@tiss.edu[1], shamin.padalkar@tiss.edu[2], gsstump@mit.edu, prayas.sutar@tiss.edu, arunachal.kumar@tiss.edu

Students and adults struggle to understand the explanations of simple astronomical phenomena. Research has shown that much of the difficulty lies with students' difficulty to use visuospatial reasoning. Drawing on research on embodied cognition, multimodality and multimedia learning, a short pedagogic sequence called 'Basic Astronomy module' was designed around multiple external representations such as concrete models, gestures, role plays, animations, interactive digital games and diagrams. In the present study, we closely monitored the implementation of the module by seven teachers in government schools in Jaipur district of Rajasthan, India to study the teaching-learning process through the module and its effectiveness. In this paper, we will document the learning outcomes of the module in terms of conceptual understanding, attitudes and beliefs. Results show that students' understanding of basic astronomy concepts improved significantly after completion of the module; additionally, students' beliefs and attitudes towards science and specifically towards astronomy changed.

INTRODUCTION

Foundations of astronomy such as the model of the solar system and explanations of commonplace phenomena such as the occurrence of day and night, seasons, phases of the moon, solar and lunar eclipses are part of high school curricula in most Indian states. Earlier research in science education documents that alternate conceptions about the earth and astronomical phenomena are common among students (Vosniadou & Brewer, 1992, 1994; Padalkar & Ramadas, 2008). These alternative conceptions are often retained after instruction, or sometimes new alternative conceptions are developed (Bailey, Prather, & Slater, 2004; Lelliott & Rollnick, 2009). Thus many adults, including teachers, have alternative conceptions in the area of astronomy (Raza, 2002; Abell, 2007).

Models in astronomy, such as that of the solar system, include spatial information such as size, shape, distances, relative positions and trajectories of celestial bodies. Understanding models and explanations of commonplace phenomena such as the occurrence of day-night, seasons, phases of the moon and eclipses requires visuospatial thinking. For example, day and night are caused due to the rotation of the earth whereas the seasons are caused due to the revolution of the earth with its axis tilted. However, many students think that day and night occur due to the revolution of the earth (Vosniadou & Brewer, 1994) and seasons occur due to the change in the distance between the sun and the earth due to the earth's elliptical orbit (Lelliott & Rollnick, 2010). Thus, difficulty in visuospatial thinking is one of the main reasons for difficulty in understanding basic astronomy and emergence of alternative conceptions (Kikas, 2006; Subramaniam & Padalkar, 2009; Padalkar & Ramadas, 2010; Plummer, Kocarelli, & Slagle, 2013).

Our understanding of space is developed through the combination of visual, haptic, kinesthetic and vestibular perception. Hence, the corresponding external representations such as visual images (diagrams, photos, and animations), handling of concrete models, gestures and bodily actions should be used to teach content which requires spatial thinking. Diagrams play a crucial role in learning science and are commonly used as a pedagogic tool in textbooks and classrooms (Ainsworth, Prain & Tyler, 2011). However, diagrams are two dimensional, static and abstract (i.e. not realistic) and hence pose a difficulty to learners (Mishra, 1999). Drawing from the research on embodied cognition and multimodality, Padalkar and Ramadas (2008, 2010) proposed a pedagogic sequence of concrete models, gestures & actions (referred here as role-play) and diagrams to teach basic astronomy. Similar attempts to use the role-plays and gestures to teach astronomy are documented in Crowder (1996) and Venkateswaran & Gupta (2009). However, we adopted the sequence proposed by Padalkar and Ramadas since it weaved different spatial representations. Also, in previous research, this pedagogy was found to be effective in addressing alternative conceptions and developing a rich and accurate understanding of astronomy. Students who underwent this pedagogy also developed good representational competence (Padalkar, 2011).

The digital medium is another powerful medium which could be included in such pedagogy. Animations can overcome the limitations of diagrams to convey motion and to some extent three-dimensionality. The advantage of diagrams and gestures is that the learner can generate them. On the other hand, it is difficult to generate concrete models and animations for a learner. However, both afford a certain amount of interactivity. In addition, the digital medium can provide instant automated feedback and if the feedback is detailed and appropriate students can use it to learn. Keeping the general theme in mind, we selected some part of the pedagogic sequence proposed by Padalkar and Ramadas (2008, 2011) and added digital activities to the module. The activities suggested by Padalkar and Ramadas (2008, 2011) were appropriated in such a way that they complement the digital activities and the module was more suitable for large-scale implementation. The purpose of this paper is to describe an intervention that utilized a combination of technology and embodied pedagogic strategies to improve high school students' understanding of basic astronomy concepts. Additionally, we examined changes in students' attitudes and beliefs about astronomy. The intervention was implemented as part of a large-scale initiative targeted toward government schools in four states of India. This work is significant in that it strives not only to mitigate a problem common to high school students in general, but it seeks to do this in a population that is under-resourced and often under performing.

METHODOLOGICAL APPROACH/ MODULE DESIGN AND CONTENTS

The module was developed via iterative design and development phases. Several classroom and individual trials were done during the development phase of the module (Chopde & Padalkar, 2018). The first round of implementation took place in Grade 9 classrooms of government schools in Rajasthan (documented in

Shaikh, Chopde & Padalkar, 2018) based upon which we revised the module and finalized the support material for the teachers. Both the module and the support material for teachers are available in both English and Hindi. As shown in Figure 1, the module is divided into three units. Each unit contains four lessons that last approximately 40 minutes each. Thus there are twelve lessons, comprising eight hours in all. Three out of twelve lessons are digital lessons which are to be conducted in a computer lab. The remaining nine lessons contain hands-on activities and discussions which are to be conducted by the teacher in a regular classroom. All of the lessons can also be accessed via weblink. The module used free and open software and will soon be released as an Open Educational Resource (OER).

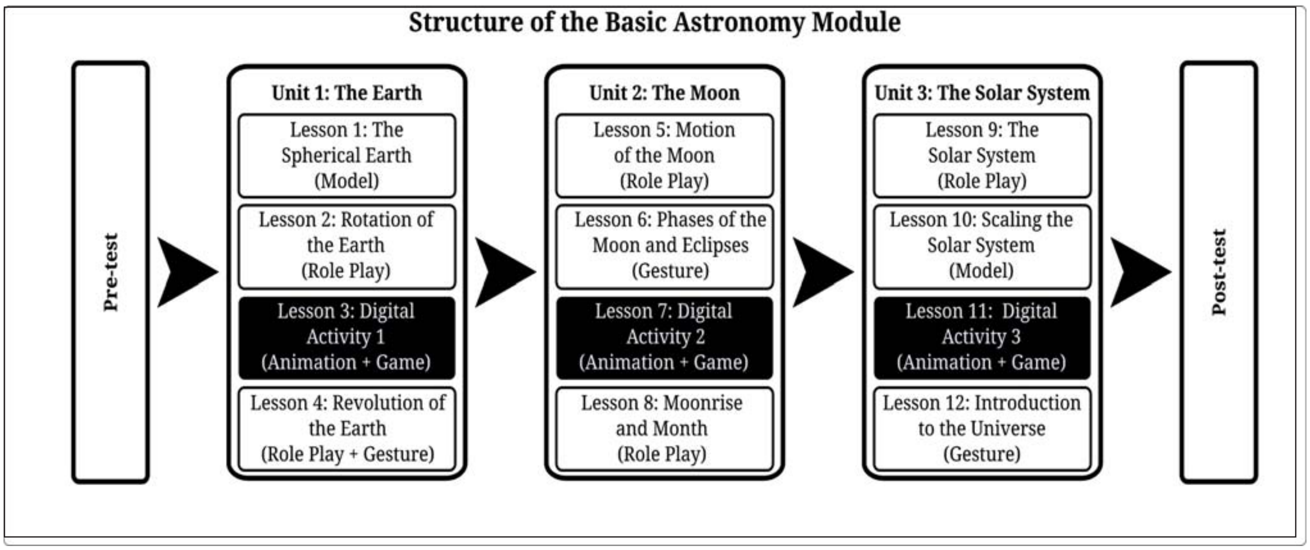


Figure 1: Structure of the 'Basic Astronomy' module

Classroom activities

As mentioned earlier, the classroom lessons consist of activities and related discussions. The number of activities focused on different kinds of spatial representations in each unit are shown in Table 1.

Unit No.	Concrete Models	Gestures	Role-plays	Diagrams (given + asked to draw)	Photos	Videos
1	3	2	5	17 + 7	0	0
2	1	1	5	11+6	8	0
3	1	1	1	3+1	23	2
Total	5	4	11	61+14	31	2

Table 1: No. of activities focused on different kinds of spatial representations

An example of use of a concrete model would be geosynchron (axis of the globe is parallel to the Earth's axis, pointing towards Pole Star). The lesson in which the geosynchron is used includes putting it in direct sunlight and observing the time of day at different locations. Examples of gestures used in the module include the right-hand thumb rule to determine the direction of the rotation and revolution of the earth and to trace the path of the sun at different latitudes and in different seasons. An example of role play is to mimic the motion of the moon to understand why we see phases of the moon. Note that different role plays were used to explain different phenomena. Most of the explanations are accompanied by diagrams, or students are required to draw a diagram after they complete the role-play activity. Photos of most of the celestial bodies which are discussed in the module are provided and two short videos on stars and galaxies are also included in the end. Teachers are expected to show the photos and videos in the classroom and to initiate appropriate discussions about them.

Digital activities

We used the multimedia principles of Mayer (2014) as guiding principles to design our digital content. All digital lessons are divided into two activities. In the first activity, students see animations. The animations include representations from different perspectives (to convey the three-dimensional nature of the systems) and mainly emphasize the motions of the celestial bodies. Some of the animations also morph into diagrams to help students see the correspondence between an animation and diagrams they regularly see in textbooks and classrooms. The second activity of the digital lesson includes a digital game called AstRoamer (divided into three parts, one part for each unit). The details of the digital activities are shown in Table 2.

Unit No.	Lesson No.	Activity 1: Animation	No. of Animations	Activity 2: Game	Astronomy Concept	No. of demos + No. of clues
1	3	Rotation of the earth	4	AstRoamer: What's the time	Rotation of the Earth and time of the day	1 + 7
2	7	The motion of the moon	3	AstRoamer: Moon Track	Phases of the moon	1 + 7
3	11	Solar System	4	AstRoamer: Planet Trek	characteristics of planets	0 + 10

Table 2: Details of the digital lessons

Apart from multimodality to facilitate the visuospatial thinking which is crucial in learning astronomy, three more guiding principles directed the design of the module: Collaborative Learning, Authentic learning and Learning from mistakes.

Collaborative Learning: Most activities in the module are to be done in pairs or groups. For example, in Roleplays students become different celestial bodies and mimic their motion. Given that the school labs have a limited number of computers (typically 10) and the number of students is at least 20, we expect that two students will use one computer when they are in the computer lab for the digital lessons. We have deliberately designed the first part of the digital game (AstRoamer: What Is the Time?) for two students to answer alternately so that students can discuss while solving the problems, and hope that it will set the trend for the rest of the activities.

Authentic Learning: India has a rich tradition of astronomy and has a variety of calendars (some are lunisolar some are lunar and some are solar). Since most of the festivals fall on a particular phase of the moon, students are well aware of the calendar used in their area. We tried to bring this aspect to the module by explaining terms used in the indigenous astronomy and designing the second part of the digital game (AstRoamer: Moon Track) around phases on different festivals. Incidentally, the terms used in indigenous astronomy and astrology are the same. We hoped that explaining them will demystify them and help students to think rationally about the astrological claims.

Learning from mistakes: In the digital game (AstRoamer), each trial has two chances. Case-specific feedback is designed which appears after the first wrong answer to help students find the correct answer. Teachers were also encouraged to ask open-ended questions to students and use their incorrect responses are resources to engage in the discussion rather than giving immediate feedback in terms of right or wrong.

STUDY PROCEDURE

For this study, we chose thirteen schools in Jaipur district with the following criteria of selection:

1. The number of students in the class was less than 40.
2. Computer lab had a minimum of 9 terminals working.
3. Schools were not too far from Jaipur to allow for classroom observations
4. Teachers were willing to participate: To ensure the authentic implementation of the module it was necessary that the teachers teach the module in their respective schools instead of allowing designers or experts to teach it.

The teachers from the selected treatment schools had access to the module on their school computers, and we also provided a hard copy of the support material two weeks before the study started. However, we anticipated that teachers would not be familiar with the module by the onset of the study and would also require on-site support. Prior to the study start date, we held a face to face workshop in which we took the teachers through half of the module in the same way the students would experience it. Out of 13 teachers who indicated interest in the study, only eight teachers attended this workshop, so we reduced our treatment sample to students in those eight schools.

Students completed a pre-test before the implementation of the module in their classes. The pre-test included 20 questions based on the content covered in the earlier grades or things that students would know from simple observations or social interactions (19 multiple choice questions, one question which required students to draw a diagram), 5 questions on attitudes towards science and astronomy and two questions related to beliefs regarding astronomy. In the next 6 working days, teachers were asked to teach the first six lessons of the module (approximately one each day). We held another workshop for teachers on the seventh working day to cover the remaining half of the module with them. We also shared pre-test results with the teachers and highlighted the major difficulties which their students faced. Seven out of the eight original teachers attended this workshop; thus we continued the study with those seven teachers and their respective schools, leaving data from seven participating schools for analysis. The study was concluded with the post-test and teacher interviews. The first 20 questions of the pre and post-test were equivalent; the post-test contained 5 extra questions on the content which was not taught in earlier grades but covered in the module. The study procedure is summarized in Table 3.

Teachers attended the first face-to-face workshop	
Student Pre-test	
* Teachers taught and students engaged in the Basic Astronomy module * Minimum two classes were observed by CLIx team member * Observed classes and teacher interviews were audio recorded	* A second face to face workshop for teachers was scheduled after half of the module was implemented (i.e. on the 7th working day). * The total number of working days between the pre and post-test (excluding the days of workshop) was 11 or 12 (typically included 12 lessons).
Student Post-test	

Table 3: Study Procedure

The study also included a control group but we have not included that part of the study considering the limited scope of this paper. The procedure and findings of the larger study are documented in more detail in TISS (2019).

SAMPLE

Grade 9 students of seven government schools from the Jaipur district of Rajasthan, India participated in the present study (school wise breakdown is displayed in Table 4). There were a total of 243 students, 106 boys and 137 girls, who participated in the study. The age of the students was between 13 to 15 years, and most of them came from low socio-economic areas. All participating schools were from rural areas of Rajasthan. The medium of instruction in all of the schools was Hindi. However, all students spoke a dialect of Hindi called Rajasthani when not in the classroom; inside the classroom most of the time they spoke in 'standard' Hindi.

School	Students		Total Number of Students	Teacher
School A	10 Boys	11 Girls	21	1 Female
School B	19 Boys	23 Girls	42	1 Male
School C	26 Boys	22 Girls	48	1 Male
School D	17 Boys	22 Girls	39	1 Female
School E	0 Boys	25 Girls	25	1 Female
School F	25 Boys	16 Girls	41	1 Male
School G	09 Boys	18 Girls	27	1 Female
Total	106 Boys	137 Girls	243	4 Female, 3 Male

Table 4: Sample details

A total of seven teachers, 4 females and 3 males, participated in the study. They all taught science subjects to grade 9 students. None of them had a physics background, some of them studied biology, and others studied chemistry during their graduation. Every year they were required to teach a chapter on basic astronomy to grade 9 students as it is part of their syllabus. Both students and teachers had rich cultural knowledge of several astronomical phenomena as there are many stories, rituals, and festivals around those phenomena.

Q. no.	Question
1	Every day at noon, the Sun is exactly overhead
2	The Moon does not rotate around its own axis
3	Saturn can be seen by the naked eye (without a telescope)
4	Planets which are closer to the Sun take more time to complete one revolution than the planets which are farther away from the Sun
5	Day and night occur because-
6	Seasons occur on the Earth because-
7	Which of these pictures is NOT a phase of the Moon?
8	The Moon rises from-
9	Mark the picture which shows the position of the sun, earth and moon at a full m oon
10	Which force is responsible for the Moon to revolve around the Earth?
11	The period from New Moon to Full Moon is called-
12	In what phase is the Moon on Diwali night?
13	Which is the brightest star in the night sky?
14	The asteroid belt is situated in between-
15	Which is the correct order from the smallest to the largest in size?
16	Which is the correct order from the nearest to the farthest from the Earth?
17	Which of the following objects produces its own light?
18	Which of the following is not part of our Solar System?
19	Which of the following is the name of a nakshatra (lunar mansion)?

Table 5: Details of questions used in figure 2

ANALYSIS AND RESULTS

This paper presents an analysis of students' pre and post-test data. Out of the 243 participating students, 169 students took both the pre and post-tests, so we included only 169 students in the statistical analysis. A dependent samples t-test was conducted to determine if students' understanding of astronomy improved after completing the module. We found that student performance on the basic astronomy test improved from pre-test (33.31%) to post-test (46.58%) and it was statistically significant ($p<.001$) with an effect size of 0.81.

A breakdown of the test questions that were similar showed that out of 20 questions, students' performance in 13 questions showed more than 10% improvement, performance in 5 questions showed no improvement (+ or - 5%), and performance in 2 questions showed negative improvement (approximately 10% or more). Figure 2 shows the change from pre to post-test for each question.

The pre and post-tests also had questions to probe students' attitudes and beliefs. As shown in Figure 3, students' attitudes toward science and specifically toward astronomy did change. Students reported slightly more positive views toward science after the intervention, in that fewer students strongly disagreed with the statement, "I enjoy learning science". Additionally, fewer students disagreed and more students agreed with the statement saying that science should be used when making decisions in everyday life, which suggests that students saw value in science even though some of them did not enjoy learning science. After completing the module, students indicated an increased interest in astronomy to the extent that some of them want to continue learning astronomy even after graduating from the school. More students said they would like to engage in astronomy related activities after completing the module (Figure 4). The number of students who said they did not like astronomy decreased slightly.

The module failed to have any impact on students' beliefs about the impact of astronomy on their life. At three different places, students reported that they think planets have an impact on their lives, eclipses are bad omens, or that they engage in making horoscopes and astrology (Figure 4, option D and Figure 5)

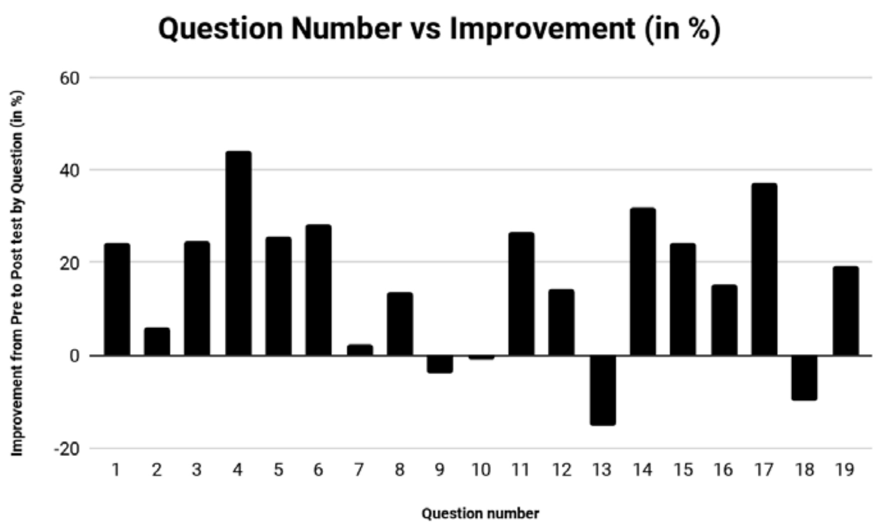


Figure 2: Question number vs Improvement from Pre to Post-test by Question. (Details of the questions are in table above)

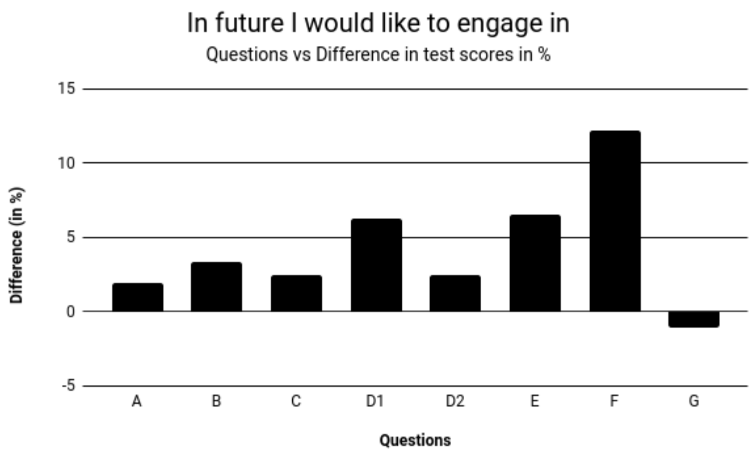


Figure 3: Students response to the following five questions regarding attitudes towards science and astronomy: A. I enjoy learning science, B. Scientific thinking should be used in taking decisions in everyday life, C. I find astronomy interesting, D. I would like to continue to learn astronomy in college (after 10th grade)

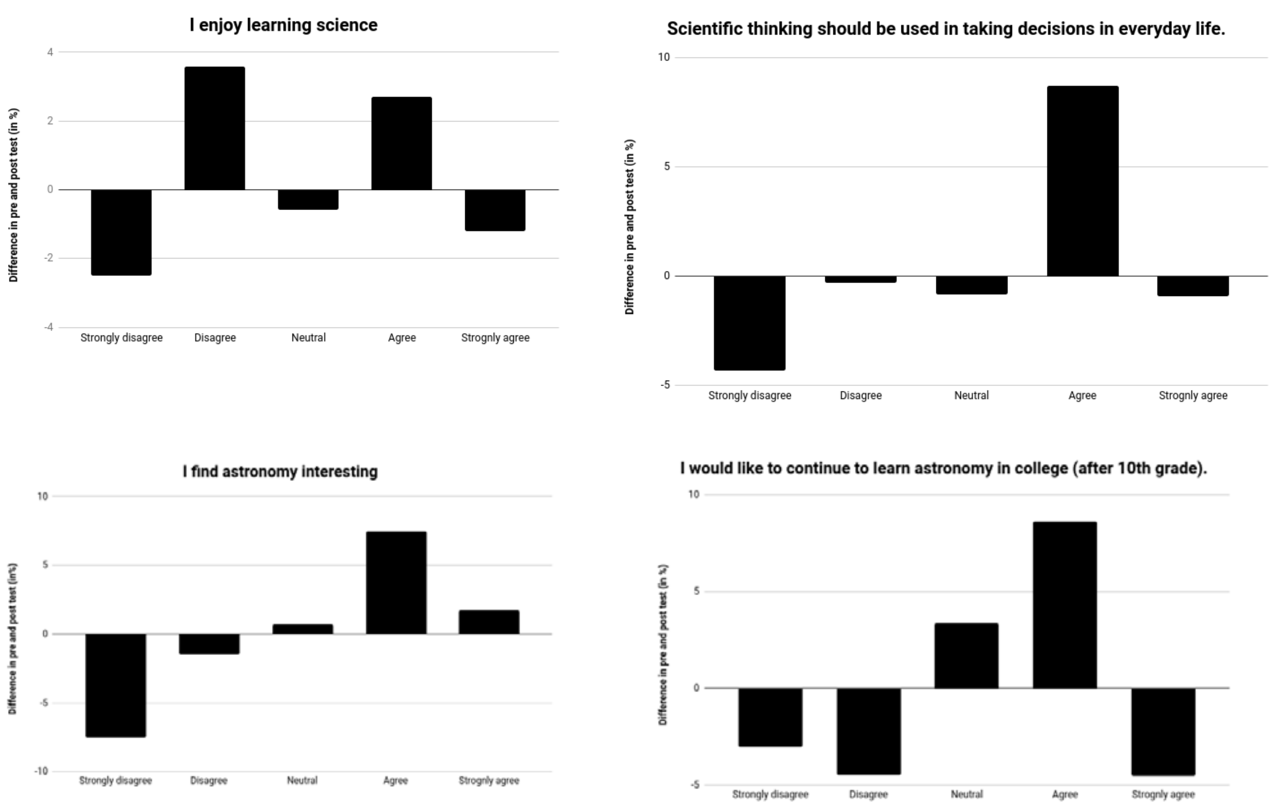


Figure 4: Students response to the question ‘ In future I would like to engage in:’. (Options: A. Observations of the moon, sun, stars and other astronomical objects, B. Learn more about different theories such as the formation of stars and solar system, C. Drawing pictures and making films about astronomy, D1. Preparing telescopes, satellites and other instruments, D2. Horoscopes and astrology, E. Doing calculations of orbits, energy etc, F. Studying how astronomy was developed in different parts of the world, G. Not interested in astronomy)

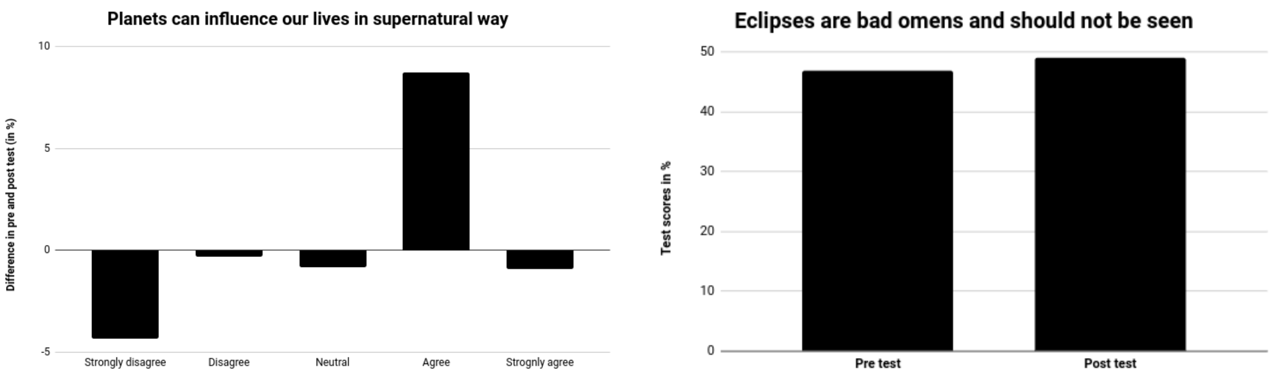


Figure 5: Students response to the following questions regarding beliefs: A. Planets can influence our lives in a supernatural way. B. Eclipses are bad omens and should not be seen

CONCLUSION AND DISCUSSION

A 'Basic Astronomy' module was designed to teach important astronomy concepts to students. The aim of this study was to investigate the impact of the module in changing students conceptual understanding, attitudes, and beliefs. A significant improvement in students' scores shows the module's effectiveness and robustness in the field. The module was also successful in changing some of the students' reported attitudes and beliefs towards science in general and astronomy. After engaging with the module, students reported positive changes in attitude toward science and astronomy, and reported increased interest in astronomy related activities. But such changes were not reported in the case of beliefs. More specifically, the beliefs which are part of the culture - the beliefs related to astrology— were not changed. It seems that such deeply held beliefs cannot be changed just by improved conceptual understanding, or change in another related belief. For example, after doing the module, more students believed that science should be used in everyday decision making but students did not view this as a conflict with making decisions related to astrology.

Lelliott & Rollnick (2010) mentioned in their extensive review that most studies in astronomy education do not refer to any particular framework. The study and other similar studies are significant because they systematically derive pedagogic ideas from an emerging framework such as embodied cognition and provide evidence of its effectiveness which in turn confirms the merit of an emerging cognitive theory. Furthermore, although many innovative pedagogies are effective in controlled settings, scaling them is challenging, particularly in disadvantaged settings. These results are important because they demonstrate that innovative pedagogies can be designed and implemented with the help of technology. It must be noted that four of the authors on this paper worked extensively with the teachers for more than three weeks to prepare them to implement this module and teachers spent considerable amount of time and efforts to improve their content and pedagogic content knowledge, but that will be the topic of another article. However, it is worth mentioning that the teachers who were initially skeptical about this new (and somewhat time consuming) pedagogy, were thrilled after going through the experience. We hope that both cognitive theories and educational technology will find practical applications through pedagogies designed for large scale implementation and the coming years will see more papers which document the challenges faced during implementation, their practical solutions and data from disadvantaged - or rather, differently advantaged - settings.

REFERENCES

Abell, S. K. (2007) Research on science teacher knowledge. *Handbook of Research on Science Education*. Abell, S. K and Lederman, N. G. (Eds.) 1105-1149.

Ainsworth, S., Prain, V., & Tyler, R. (2011). Drawing to learn in science. *Science, 333,* 1096-1097.

Bailey, J. M., Prather, E. E., and Slater, T. F. (2004). Reflecting on the summary of astronomy education research to plan for the future. *Advances in space research*, 34:2136 – 2144.

Chopde, S., Padalkar, S 2017. Astronomy Education: A Case for Blended Learning. *Paper presented at National Conference on ICT in Education Perspectives, Practices and Possibilities, Mysuru, Swami Vivekananda Youth Movement,* 11th-12th May 2017.

Crowder, E. M. (1996). Gestures at work in sense-making science talk. *Journal of the Learning Sciences, 5*(3), 173–208.

Kikas, E. (2006) The Effect of Verbal and Visuo-Spatial Abilities on the Development of Knowledge of the Earth. *Research in Science Education*, 36: 269–283.

Lelliott, A., & Rollnick, M. (2010). Big ideas: A review of astronomy education research 1974–2008. *International Journal of Science Education*, 32(13), 1771-1799.

Mayer, R. E. (2014). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), Cambridge handbooks in psychology. *The Cambridge handbook of multimedia learning (pp. 43-71)*. New York, NY, US: Cambridge University Press.

Mishra, P. (1999). The role of abstraction in scientific illustration: Implications for pedagogy. *Journal of Visual Literacy*, 19 (2): 139-158.

Padalkar, S. and Ramadas, J. (2008). Indian students' understanding of astronomy. *In Electronic Proceedings of Conference of Asian Science Education (CASE2008)*, Kaohsiung, Taiwan, February, 2008.

Padalkar, S. and Ramadas, J. (2010). Designed and spontaneous gestures in elementary astronomy education. *International Journal of Science Education.* 33(12), 1703-1739. DOI:10.1080/09500693.2010.520348

Padalkar, S. (2011). Visualization and Spatial Cognition in Elementary Astronomy Education. Unpublished Ph.D. Thesis.

Plummer, J. D., Kocareli A., & Slagle C. (2014) Learning to Explain Astronomy Across Moving Frames of Reference: Exploring the role of classroom and planetarium-based instructional contexts, *International Journal* *of Science Education*, 36:7, 1083-1106

Raza, G., Singh, S., and Dutt, B. (2002). Public science and cultural distance. *Science Communication*, 23(3):293 – 309.

Shaikh, R., Chopde, S., & Padalkar, S. (2018). Teaching and Learning Basic Astronomy Through a Blended Module. In Hye-Jung Lee ((Eds.), *Proceedings of the 8th Annual International Conference on Education and E-Learning (EeL) 2018*, *Singapore*, *127–133*. Singapore: Global Science and Technology Forum (GSTM).

Subramaniam, K. and Padalkar, S. (2009). Visualisation and reasoning in explaining the phases of the moon. *International Journal of Science Education*, 31 (3), 395-417.

TISS (2019) Unpublished Report on Learning Outcomes of CLIx Student Modules available at https://clix.tiss.edu/wp-content/uploads/2015/09/LO_Report-2019.pdf

Venkateswaran, T.V. and Gupta, A. (2009) *Basics of Astronomy through Role Play: Handbook for science activists and teachers.* Bharat Gyan Vigyan Samithi, New Delhi.

Vosniadou, S. and Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, 24:535–585.

Vosniadou, S. and Brewer, W. F. (1994). Mental models of the day/ night cycle. *Cognitive Science*, 18:123–183.

MODELLING IN DESIGN-AND-MAKE: SYNTHESIS OF A BIOLOGICAL CELL INTO A BOARD-GAME

Ritesh Khunyakari
Tata Institute of Social Sciences, Hyderabad, India
ritesh.k@tiss.edu

Modelling is an integral part of the design-and-make experience. The translation and use of knowledge from one domain to develop a production in a different domain requires deeper engagement. This paper reports a pedagogic experiment involving social science undergraduates designing and making a board game for secondary schools students to help understand a biological (animal or plant) cell. Analysis of board games revealed two forms of engagement with modelling: abstractive and transformative. Models that captured the essential features generalisable of a typical cell into a different form of representation were identified as abstractive kind. Other cell models which extracted conceptual ideas and re-represented them into a distinctively different form, opening newer ways of imagining were classified as transformative. The study offers insights into how modelling enriches conceptual learning and exemplifies possibilities of integrating design-and-make in higher education.

DESIGN-AND-MAKE AS VALUED CONTEXT FOR LEARNING

The contemporary educational discourse aims at making school learning meaningful and engaging. The proposals for integrating design and technology (D&T) education within the ambit of school education are receiving greater reciprocation from diverse stakeholders. Design-and-make units have potentials to provide relatable contexts for inquiry and learning (Baynes, 2010; Kimbell & Stables, 2007). They provide opportunities for simultaneous immersion into knowing, doing, meaning-making and transcending knowledge across disciplinary boundaries (Khunyakari, 2019). Studies within the global (Banks & Barlex, 2014; Crismond & Adams, 2012) and the Indian context (Khunyakari, 2015) vouch for curricular and cognitive gains through an integration of design-and-make in school curricula. The learning processes involved align with naturalistic patterns of human learning rather than knowledge presented as piecemeal, isolated bodies of information. More importantly, design-and-make experiences have scope for developing creative ingenuity, empathy, critical reflection and social consciousness among individuals engaging with the learning activities.

Models and Modelling in D&T education

The process of modelling is an inseparable part of design and technology endeavours (Elmer 1999; Welch, 1998; Davies, 1996). Roberts, Archer & Baynes (1992) argue that modelling plays an equivalent role of language in the process of designing. Barlex (1991) hints at the role of model, different from physical artefact or end in itself, serving as an aid to reveal pupil's thinking. While acknowledging instrumentality of models, Liddament (1990) argues the need to distinguish use of models as 'information carriers' from those serving teaching function. Teaching, which involves supporting learners in identifying and elaborating the underlying conceptual structures, through modelling has been less researched. Smith (2001) proposes categorisation of models into three kinds, namely; *iconic* (representing a product or part of it, e.g. drawing or 3D model of kettle handle), *analogue* (diagrams using symbols to represent a system or product, e.g. electronic circuits) and *symbolic* (using abstract code to represent aspects of an existing or possible product or system, e.g. mathematical model of a bridge). Archer (in Roberts et. al., 1992, p.9) argues 'humans construe sense data and construct representations spatially and presentationally, rather than discursively and sequentially.' He asserts that 'cognitive modelling' is unique to designing, enabling one to form images in the mind's eye, and have capabilities to operate, manipulate and evaluate them.

RELEVANCE OF THE STUDY

The efforts directed towards understanding learning processes resulting from an assimilation of cross-cutting concepts are increasingly gaining recognition (NGSS, 2013). Several studies attempt to identify and underscore the connections across disciplines by inquiring into the nature of disciplinary knowledge brought to bear in a particular unit or activity. However, such a fact-finding exercise does not serve much beyond the purpose of validation. In such studies significant ideas related to practice, such as, the quality of connections made, the kind of support afforded, forms of assessment used, etc. do not become explicit. In other words, the qualitative nature of the conditions that afford learning remain hidden. For instance, the contexts that stimulate individuals to pursue a concept from across domains (of knowledge), either by morphing or radical transformation of seed ideas into meaningful outcomes in another domain (of use), are seldom investigated. Such experiences provide the necessary hooks to anchor possibilities for re-thinking about teaching. No matter how raw in their character, studies involving practice and 'pedagogic experiments' have the potential to offer valuable insights into the cognitive realm of human learning involving interactions with problem scenarios, knowledges, and collaborative action. Although experiences of D&T education for primary and secondary school students have been well documented, there are sparse reports of design-and-make at the higher education level, particularly in the Indian context. An increasing emphasis on subject specialisations and disciplinary streaming in higher education offer little opportunities for exercising the use of cross-cutting concepts. The pedagogic experiment reported in this paper invited social science undergraduates to venture around a central concept in life sciences (otherwise considered outside their domain space).

OBJECTIVES OF THE STUDY

Since the study involved teaching, the primary objective was to transact conceptual understanding of structure and functioning of biological cell and its internalisation in a meaningful way among social science undergraduates. The research objectives addressed are:

1. To investigate the worthiness of design-and-make experience for engaging social science undergraduates to think about fundamental concepts in the sciences.
2. To study the conditions and evidences structured around the design-and-make experience that provided opportunities for learning.
3. To critically examine students' work, their reflections and the resulting learning outcomes from being involved in the process.

THE STUDY

The study involved a 'pedagogic experiment' at the interface of teaching, development and reflective analysis. Social science undergraduates, after an exposure to foundational ideas around biological cell, were invited to collaboratively design-and-make a board-game that would help teach the concept of biological cell to secondary school students.

Participants

The participants were 60 students, enrolled in the B.A. in Social Sciences (BASS) programme at the University, where the author taught participants a 2-credit (30 hours of teaching), core course on Introduction to Life Sciences. The undergraduate programme had a mix of students from the arts, commerce and science streams. They represented diverse cultural and linguistic exposure, from across India. Usually participants in this programme come with a disinterest for the sciences and aim for a career in social development sector. Addressing the disinterest towards the sciences and seeking a relevance between the sciences and the social sciences in the first year of BASS poses challenges. The participants volunteered to work in 16 teams, each consisting of 3 to 4 individuals. Teams attempted to have a fair representation of genders, alignment interest in pursuing either an animal cell or a plant cell, and have at least one member who had studied biology at the higher secondary level. The criteria helped the teacher-researcher maintain some form of parity across teams. Individuals within each team engaged themselves in the task during break-time, after their class hours, and over weekends.

Nature of the engagement

The author, a teacher-researcher, has been teaching the course for the last 6 years. The data for this study is from the academic year 2017-18. The course aimed to develop an appreciation of fundamental ideas in life sciences that have contributed to the advancement of human knowledge and to the development of society. Going beyond just explaining the concepts, the pedagogic effort was to help students locate ideas within their historical contexts, relate to the processes involved in the discovery of scientific insights, and develop an understanding of the nature of socio-cultural and political influences shaping scientific endeavours. The breadth of ideas that can be potentially covered through such a course plan is exhaustive. Hence, the effort during course teaching was to revisit some salient ideas that not just brought a transformative character to the erstwhile knowledge but also reformed the approach to human thinking and understanding. For instance, uncovering structural foundations of life, biomolecules in complex functional existence, processes of transmission of characters (basic genetics) and change over generations (evolution). Through the process of revisiting ideas, course participants were encouraged to find relevance of ideas in contemporary contexts.

Process of the engagement

The design-and-make engagement was contingent on two kinds of 'knowing': (a) knowledge of the diverse board-games which can help trigger ideas and (b) foundations of structure and functioning of a biological cell. The participants were encouraged to use readily available resources, if possible, re-using waste materials in their immediate environment. As an initiation, a few visuals of board-games from different socio-historical and cultural contexts were shared. A trailer clip of the movie '*Jumanji*' added an element of fun and excitement. In the examples showcased, attention was drawn to features such as variety of materials, design elements like props, end-goal and norms of playing. The design-and-make task was situated within class discussions on the emergence of cell concept, formulation of cell theory as an explanation to structural organisation and procreation. Understanding biological cells invited participants to learn about organelle components, their structures, functional mechanisms, and develop knowledge about similarities and differences of a typical animal and plant cell. This content is very much a part of school science, but without the inclusion of history and social conditions that shaped the discovery of biological cells. Very often the school science projects demand learners (with support from adults) to make physical, 3D models of animal or plant cells with materials such as styrofoam. Such physical modelling is limited to a mere translation of information from standardised 2D, diagrammatic representation into a 3D, static, projective depiction. Such an act of reproduction, conceived as 'modelling', is celebrated as an outcome of knowledge about organelles and processes of a biological cell. In this study, modelling is understood differently. The designing and making of a board-game was not just a means to build and assess their understanding of concepts and skills but also a means to invoke and relate to their 'conceptual models'. The research followed the development of design ideas and realisation of board-games, on lines of a pedagogic structure of collaboration & communication centred D&T education, described in Khunyakari (2015). The outcome of this learning activity went far beyond communicative elaboration to serving a means for generating interest, enthusiasm and knowing intricate details about biological cells. While the end-products gave insights into students' understanding, the process of engagement opened up avenues to capture cognitive aspects of learning within collaborative environments, internalisation of concepts and their application into a different context.

Forms of data

The primary sources included portfolios maintained by each team, a write-up that included instructional manual for playing, and the production (board-game) itself. Team portfolios included sketches, drawings, raw ideas, information and details about biological cells, and worksheets. Following the data closely allowed noting transitions and evolution of ideas through the phases of design-and-make.

ANALYSIS AND FINDINGS

This findings are organised in two parts. A discussion on generic observations hints to conditions and evidences that triggered and supported learning. Elaborate description of two cases allows nuanced appreciation of learning.

(A) Generic observations

Out of the 16 teams, 11 teams chose to work on designing a board game around an animal cell while 5 teams worked on plant cell. The coinage of names indicated a metaphorical or an analogical connect. For instance, *Battle-via-cellula* (Understanding battles through/in cell), *Celluzzle* (The puzzle about cells), *Fort-o-chondria* (The granular castle). Translating knowledge of biological cells into board games required a command over concepts. The interests and exposure to scientific knowledge within each team varied. Often, the teams made copious notes about cell organelles, their structure and functioning. The collaborative nature of work allowed for an intermingling of concepts and skills. Collaborative discussions involved identifying symbolic salience of organelle functions and abstracting how this could be used during planning. Teams planned ‘making’ using sketches, texts and materials from their immediate environment. The participants personalised their board game as a ‘work of art’, translated ideas into material forms, calculated area and developed rubric for scoring the difficulty levels. Analysis of portfolios revealed prudent judgement by participants in tailored use of text for specific purposes like collating information, brainstorming ideas, planning changes, reflecting and reporting. Selective transformation or adaptation of known elements was driven by the following considerations: entry or exit points; envisaging the goal, levels of engagement and challenges in the game; sustaining more than two players; and scoring (goal-achieving) scheme. Teams consciously selected affordable and easily available materials such as sand, cardboard, erasers, nail paint, broken marble pieces, cloth, etc. They developed manuals for detailing rules, introducing components and props/pawns. Portable designs which could fold and fit in small spaces indicated explicit attention to ergonomics. Often the features of props, such as colours, shape and materials, aligned with the organelle features and their functions. Although board games have an implied necessity of a ‘board’, the ingenuity of participants reflected in varied use of cloth, cardboard and chart paper. The making involved a careful synthesis of details and decision-making. For instance, how many players can be involved in a game at a given point, how many flashcards need to be created and what could it contain, scheme for reward points, etc. The findings suggest fluid integration of knowledge and skills from across disciplines. Simultaneous and explicit attention to conceptual content, aesthetics and packaging reflected deep involvement and continual strive for quality outcome.

(B) Learning from two cases

Each case description includes inspirational ideas, articulated objective/s, and target audience. Aspects of manufacturing (material and resource considerations), rules, notations, and scoring rubrics developed form the second part. The last part has reflections on students’ work, observations about productions, and pointers that unfold cognitive aspects of engagement. A representation of plant and animal cell was deliberate, but the choice of cases was random.

Case 1: Cell Castle by Team *Trifolium* [Team 4]

Designed for children aged 12 years and above, this team worked on a board game plant cell to meet the dual purpose of education and enjoyment. The decisions to include a typical plant cell diagram and basic information on flash cards was rationalized as being age appropriate. The team drew inspiration from games like Snake & Ladders, Monopoly and Guess Who.

Unlike the other board games developed, which used either a chart paper or a cardboard sheet for making the primary surface, this team painted a typical plant cell on a white cloth (see Figure 1). The game had a maximum of 4 players, represented as 4 distinctly coloured pawns, stationed at four different places outside the cell and exhibited a colour correspondence. The board game was about taking each player through a journey of information about the various plant cell organelles. A roll of dice resulting in a score of either 2 or 5, entitled the player to pass through cell wall and cell membrane, pick Card 1, and occupy the “START” position. The player then passed the dice to the next player. No player gets an extra turn, either on getting the suitable position or even if the player gets lucky with 6 number upon rolling the dice. The player needs to wait for her/his turn and follow instructions provided on the card. Each flash card bore a number. The number co-ordinated cards had information about organelles and instructions that enabled a player to move forward in the game along the pre-determined path. The path of movement, identified as blocks, spanned the cell environment and also passed through organelles. Appropriate flash cards needed to be read aloud on reaching an organelle block. The game included suitable incentives and punishments (in the form of danger blocks that pull you back, painted red). The player succeeding in assimilating maximum information about cell organelles compared to her/his peers emerged as the winner.

Value considerations seem to shape designers' decisions, from the early stages of planning. The decision of providing information about organelle and its functioning through flash cards achieves the purpose of strengthening knowledge as well as retaining the fun component. Non-intrinsic (extraneous) values such as making the board game portable, cost-efficient, and environment-friendly influenced design of this product. In highlighting an interplay of knowledge and values in technological learning engagement, Pavlova (2005) emphasizes the need to be conscious of intrinsic and non-intrinsic values that shape design decisions. Further, Khunyakari (2019) argues that values considerations may take the role of primary generators during the process of designing. For instance, the self-imposed constraint of cost-efficiency translated into the need to reconfigure broken pieces of marbles into pawns by employing creative, aesthetic skills. Team's board game harnessed modelling to achieve representational access to abstract concept along with strengthened association and reinforcement of relevant information. Such a form of modelling that goes beyond just using a different medium for representation and focuses on extracting salient attributes, enriching information and aiding visuo-spatial thinking has been referred to as "abstractive modelling".

Case 2: *Étude Sur La Vie* (Study about Life) by Team MAD Creations Ltd. [Team 7].
A set of neatly packaged items in a box constituted the board game. The contents included a rectangular board folded along its long edge, a user manual, a guidebook for game-keeper, three sets of flash cards, box containing cell organelles, and a small box with dices and pawns (see Figure 2). The board game involving 2 to 4 players and a game-keeper, designed to unfold in three levels, aimed to assess understanding about animal cell among children aged 13 years and above. Team drew its inspiration from the games as Candyland and Bookchase.

Figure 1: Board Game of Team *Trifolium*

Figure 2: Board Game of Team *MAD*

The game had three levels. Level 1 invited players to roll the dice to get an appropriate score for choosing a card. Answering correctly the question on the card would establish a claim to cytoplasm (represented as circular structures covered by fine sand). A correct response would yield the packet of cell organelles, which the player needed to place on the cytoplasm in order to complete the model of animal cell. For each of the cell organelles, the game keeper would raise questions. The completion of this level takes the player to the next level. In Level 2, the player needs to roll the dice to a number to secure a molecule. The player in the next turn needs to get the right number on dice to choose the specific transport mechanism for their organelle. Since organelles have specific transport systems, getting a correct transport system is critical to the movement of the molecule across the semi-permeable membranes. If the player succeeds in achieving the right number, corresponding to the system, the pawn makes an entry to the cell system, taking the player to the last level. In Level 3, the player needs to pick up cards, one at a time. These cards contain instructions and some (negative or positive) points. For instance, a waste material card yields some negative points whereas cue card for vacuole allows the player to eliminate all waste material cards to vacuole since vacuoles in animal cells store wastes. As a result, the player would now have only positive points. The player with maximum score, among the four, would be the winner. Gradual progression across levels beginning with developing an understanding of cell components through a piecemeal assemblage in Level 1 to internalising the mechanism of transport for molecules in Level 2 to associating an understanding of form and function in Level 3, retains the dual purpose of sustaining interests and building levels of knowledge. The considerations of material cost and expenditure in making, remained with the team from the initial design until the production stage. A judicious choice of local materials, such as, papermash, clay, etc. and re-use of resources as “Old Amazon Box”, Pasta box, etc. while estimating budget and during making is suggestive of economic consideration in play design. Students’ ingenuity got expressed at various stages. For instance, in choosing a latin name for their board game to deriving the acronym ‘MAD’ from first letters of their names. Further, the game architecture used materials that capture organelle characteristics, colour coded scheme, and scoring rubric that symbolised aspects of organelle functioning. For instance, in Level 3, if a player gets a lysosome in her/his card, s/he must keep her/his pawn outside the cell and go back to Level 2. Participants’ conscious use of rules aligned with conceptual understanding of processes in animal cell functioning. Such an extension of knowledge to model the movement of a biomolecule across organelles within cell is an exemplification of transfer of knowledge. Haskell (2000) argues the need for creating opportunities that necessitate transfer of learning by recognising and extending opportunities of engagement to novel contexts and situations.

The norms set for fair play are critical to any board game. Analysis of these reveal the degree to which human actions were anticipated. Hence, rules of game and the scoring scheme together provided the framework for optimising cognitive engagement during play activities. For instance, an anticipation of a limited number of cards as cues made participants frame two constraints as rules. The first constraint was to read the cue card quietly and not share it with the other player. They could, however, talk aloud the answers. The time limit of two minutes per question served as the second constraint. Both constraints demanded a continual, focused engagement of players. Serious attention to details was noted not just in designing the product, but also in its packaging. Symbols for handling, the bar code and the label of manufacturing, all brought a professional character to the finished product. The team’s use of modelling to gain a focus on conceptual ideas by re-representing existing understanding into distinctively different forms thereby opening scope for questioning and challenging ideas and initiating search for deeper knowledge has been referred to as "transformative modelling". Through modelling, this team attempted to surpass the goal of strengthening or associating information to creatively recasting the content in a manner that renews or alters possibilities of thought, invoking a deeper knowledge of cell.

CONCLUSIONS AND THE WAY FORWARD

The pedagogic experiment invited social sciences undergraduates to collaboratively design a board game as a means to revisit cell concept and develop context for extending understanding. In conventional teaching, knowledge about cells is packed as information. Designing a board game presented participants with an opportunity to 'model' understanding and balance learning with fun. Participants' engagement with design-and-make of board games, without an orientation or exposure to principles of creating board games, elicited two kinds of modelling, which have been referred to as abstractive and transformative modelling. Case 1 exemplifies abstractive modelling where the team seemed to have used modelling for representational access along with reinforcing the relevant information. On the other hand, Case 2 represented transformative modelling, where the team's effort was on re-representation into an altered form that explored conceptual ideas and affording scope for operating on knowledge and refining it further. Analysis of the varied associations related to the processes of modelling in the context of this study also hints to a complex interplay of intent and knowledge, which needs to be pursued further. The context of play allowed exploration of a variety of board games, some of which have deep-seated, cultural histories. Although the dimension of culture has not been focused in this study, the data suggest the role of cultural exposure as an influence on design development. Tapping the experience for uncovering alternative conceptions related to understanding cells and mental models that participants operate upon would be an interesting dimension of inquiry that can be pursued further.

ACKNOWLEDGEMENTS

Sincere thanks to participants who willingly and enthusiastically reciprocated to the design-and-make experience and to TISSH for the opportunity to conduct the pedagogic experiment.

REFERENCES

Banks, F. & Barlex, D. (2014). *Teaching STEM in the Secondary School: Helping Teachers Meet the Challenge*. London: Routledge.

Barlex, D. (1991). A comparison between the nature of modelling in science and design and technology. *DATER 1991 Conference,* Loughborough: Loughborough University.

Baynes, K. (2010). Models of change: The future of design education. *Design and Technology Education: An International Journal*, 15(3), 10-17.

Crismond, D. & Adams, R. (2012). The informed design teaching and learning matrix. *Journal of Engineering*

Education, 101(4), 738-797.

Davies, T. (1996). Modelling and creativity in design and technology. *IDATER 1996 Conference*, Loughborough: Loughborough University. https://dspace.lboro.ac.uk/2134/1476

Elmer, R. (1999). Modelling in design and technology education. *British Educational Research Association (BERA) Annual Conference*, Brighton, University of Sussex.

Haskell, R. (2000). *Transfer of Learning: Cognition, Instruction & Reasoning.* San Diego: Academic Press.

Khunyakari, R. (2015). Experiences of design-and-make interventions with Indian middle school students. *Contemporary Education Dialogue*, 12(2), 139-176.

Khunyakari, R. (2019). Analysing 'values' in collaborative development of D&T education units. In S. Pule & M. de Vries (Eds.), *Proceedings of 37th International Conference on Pupils' Attitudes Towards Technology (PATT 37)* (pp. 249-267). Msida, Malta: University of Malta.

Kimbell, R. and Stables, K. (2007). *Researching design learning. Issues and findings from two decades of research and development*. Dordrecht: Springer.

Liddament, T. (1990). The role of modelling in design and technology education. *Design and Technology Teaching*, 22(3), 153-156.

NGSS (2013). Next Generation Science Standards. Appendix G: Crosscutting concepts https://www.nextgenscience.org/sites/default/files/Appendix%20G%20-%20Crosscutting%20Concepts%20FINAL%20edited%204.10.13.pdf

Pavlova, M. (2005). Knowledge and values in technology education. *International Journal of Technology and Design Education,* 15(2), 127-147.

Roberts, P., Archer, B., & Baynes, K. (1992). *Modelling: The language of designing* (Design: Occasional Paper No. 1). Loughborough: Loughborough University.

Smith, J. (2001). The DATA Lecture - The current and future role of modelling in design and technology. *The Journal of Design and Technology Education*, 6(1), 5-15.

Welch, M. (1998). Students' use of three-dimensional modelling while designing and making a solution to a technological problem. International Journal of Technology and Design Education, 8(3), 241-260.