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Enhancing Content Knowledge of In-service Science Teachers through Model and Modeling

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The guiding question for this paper is; how does model and modelling enable student-teachers to develop a conceptual understanding of the cell as a structural and functional unit of living things? A teaching unit 'The Cell' was designed in view that models are a major teaching and learning tool for developing scientific thinking, whereas modelling means a process of forming representation. The teaching and learning strategies reported here encapsulated four modelling phases. *Firstly*, student-teachers modelled historical development of cell through a time line and role play and discussed the evolutionary and tentative nature of science. *Secondly*, the candy factory analogy provided a reference point to relate functional similarities between the units of a factory and cell organelles. *Thirdly*, students-teachers developed a 2D model to express their interpretation of the mental model. *Fourthly*, they critiqued their 2D model to develop a 3D model. Overall, a progression of conceptual understanding with distinct phases of enacting, building and rebuilding helped student teacher to conceptualize the structure and function of cell. Pre-post tests results show marked improvement in student-teachers' content knowledge on various aspects of structure and function of cell. Furthermore, teachers appreciated the effectiveness of the modelling process in enhancing their content knowledge and helping them develop understanding of the nature of model and modelling. Teachers also acknowledged the model as an effective teaching tool, which they could use in their classroom.

Keywords: content knowledge, in-service, science teacher, model and modelling

Introduction

The world is advancing very fast and knowledge is growing exponentially. Science and technology have contributed much towards creating an advanced complex society. In response to such progression, the school has to play its critical role in equipping children with the advancing knowledge and skills. The aim to prepare students to cope up with the challenges of the society is not possible without skilled teachers. Teachers need to have good content knowledge, to help students develop a better understanding of concepts and address students' misconceptions (Hammond, 1998; Bishop & Denley, 1997).

It is found that science teachers are not confident in adopting interactive ways of teaching and seriously lack subject matter knowledge (Saeed & Mahmood, 2002; Pardhan & Babur, 2009), hold a number of misconceptions and transmit onto students (Yip, 1998). Hence, they adopt the transmission mode of teaching and promote rote memorization (Pardhan & Wheeler, 2000; Hoodbhoy, 1998).

Hammond (1998) has emphasized that the teacher needs to understand subject matter deeply and to connect the ideas across fields and to everyday life. This level of understanding is essential to develop pedagogical content knowledge (Shulman, 1987). Therefore, teacher education programmes in Pakistan should emphasize the development of the teacher's conceptual understanding of content and a repertoire of contemporary pedagogical knowledge specific to their subject areas.

The Aga Khan University Institute for Educational Development has taken initiatives to develop the cadre of teachers that can bring change in teaching-learning process in their school. These student-teachers participate in a two year in-service Master in Education programme to become reflective practitioners, classroom researchers and life long learners. Each participant has to attend some core courses, specialization courses in the area of educational leadership or teacher education and conduct a small scale research. The science specialization teacher education course exposes and engages students-teachers with current theories and issues in science education and teaches science topics in the light of current approaches of teaching and learning. (MEd Programme Resource Guide, 2011). However, different course reports have identified that student-teachers have inadequate content knowledge. During the teaching practicum, course facilitators found that student-teachers feel it difficulty in handling unexpected and varied students' responses. Hence, the reports recommend to in-build more content enhancing strategies in the courses.

Each year specialization in science course is designed in light of the course aims, last year's reflection and course reports to teach fundamental and contemporary concepts along with specific pedagogies. It is important to mention that the course participants are practicing science teachers and they have to implement national science curricula in their classrooms. Therefore, national science curricula are also consulted while designing the course. Analysis of curricula reveal that general science curriculum grade IV-VIII aims to develop scientific literacy among students by helping them to develop knowledge and coherent understanding of the living and physical environment. It demands teachers to play significant role in helping students achieve scientific literacy.

Specifically, the biology curriculum for grade IX-X has been designed with emphasis on reasoning and conceptual grasp at every stage and permits clear and sequential flow of concepts. Furthermore, the curriculum IX-X has provided conceptual linkages between cellular organization of plant and animal from grade VI to the cell structure and functions for grade XII; have identified the model as an effective tool to describe the structure and functions of cell organelles in terms of life processes and have suggested providing training to the teachers in teaching of science and developing teaching materials to meet the challenges of science education. (National Curriculum of General Science for IV to VIII and IX-X, 2006).

In view of the identified needs, national curriculum demands and student-teachers; desire to improve content knowledge, the science course reported here was planned as part of science course to teach the cell, through models and modeling strategies, to enhance content and pedagogical content knowledge of teacher to teach the topic. Against this background, our overall driving question was; how does model and modelling enable students-teacher to develop a conceptual understanding of the cell as a structural and functional unit of living things?

Theoretical Underpinning

This section aims to describe a two fold theoretical framework that guides this paper. Firstly, cell is a fundamental yet abstract concept of biological science. Secondly, model and modeling can be used as a useful teaching and learning strategy to teach abstract concepts like structure and function of cell.

Cell, fundamental biological concept

The cell is a fundamental and important

concept in biological science (Trigidgo & Ratcliff, 2000). That is why the basic understanding of the cell structure and functioning is recommended to be essential to understand the functioning of the multicellular organisms. The majority of the higher concepts in biological sciences are based on fundamental knowledge of cell. Considering the cell as a fundamental topic, it is usually presented in the textbooks across different levels (McComas, 2007). The content progresses in more detail as the topic progresses from lower to higher grades.

It is also found that cell is usually placed as initial chapter in the biological portion of the textbooks. However, cell is characterized to be a difficult concept to understand by the students at different educational levels.

The situation becomes more complicated when the school teachers lack coherent understanding of the cell (Douvdevany, Dreyfus and Jungwirth, 1997). As a result such students carry with them some alternative frameworks related to different life processes. In the absence of this basic understanding it become difficult for the students to understand complex processes like photosynthesis and respiration (Flores, 2003). On the same note, there are a number of misconcepts associated with cell shown by students like; confusion of cell with molecule as a small indivisible unit, confusion over the size of cells, thinking that cells are only in certain parts of the human body or other living things and confusion over how cell functions (Tregidgo & Rtatcliffe, 2000, p. 54). Apart from students, teachers also find cell as a difficult topic to learn and teach because of its abstract nature and high school teachers lack coherent understanding of the cell (Douvdevany, Dreyfus and Jungwirth, 1997).

To help students understand better, researchers and classroom teachers use different approaches like model, diagrams, microscopy, analogy, posters and poems to teach difficult abstract concepts of biology. The use of a model is found to be effective in biology teaching especially at the molecular and cellular level. Lock (1997) reports that, while preparing and manipulating the model, students visualize and readily understand the processes that occur at molecular level. Apart from model use, poster and poems are equally significant. Another strategy which is widely used by the researcher and classroom teacher is to observe plant or animal cell under microscope. Through microscopy shift from macro level (living things) to micro level (a cell taken from living things) can be made easily. In this way it is easy to build link that living things are made of cell. Sometimes, while teaching cell, some teachers introduce cell from microscopic perspective (by showing cell under microscope) and then relate with the living things, from micro to macro level. Crook and Sheldon (2005) disagree with this idea to start the topic with an exposure to the microscopic world.

Model and Modeling: A strategy to teach cell

Model and modeling have gained a significant place in science. The use of the model facilitates the visualization and understanding of abstract ideas and represents what cannot be seen (Trigidgo & Ratcliff, 2000) especially at molecular and cellular level (Verhoeff, Waarlo & Boersma, 2008). It helps to build links between theory and practice, as theory can be situated into world-as-experienced through the help of model (Gilbert, 2005; 2001; 1998). Models are considered to be one of the main products of science; models are major teaching and learning tool in science education while modeling is an important element in scientific methodology. Gilbert has built a linkage between model and modeling. Model is representation of idea, event or object (the target) based on some familiar one (source) whereas modeling is the process of forming a representation (Gilbert 1993). For example, the structure of atom (target) can be explained by referring to the arrangement of planet around sun in solar system (source) to build conceptual model of atom.

Modeling is an important aspect of science teaching. Gilbert (1993) mentions four major roles of modeling:

- Models can simplify complex phenomenon;
- Models can aid understanding allowing ideas to be tested in a new situation;
- Mental models can offer to insight into fundamental nature of the phenomena;
- Analogical models can interpret scientific phenomenon to the students.

In a modeling project, Tregidgo and Ratcliffe (2000) found that 3D modeling provided better cognitive development chance as compared to 2D modelling. 70% of 3D modelers achieved accepted responses which was true for 50% of 2D group. In addition, 3D modelers recalled facts about cell parts and their function, offered a greater number of specialist term as compared to 2D modelers. Overall the process of modeling supports in describing or explaining processes, events or entities.

Models are widely used in major areas of science. Hence typologies of models are developed to characterize selected model like: scale models, analogue models, mathematical models and theoretical models (Parkinson, 2004). Ontologically, models can be classified as mental, expressed, consensus, scientific, historical, curricular, hybrid and teaching models (Gilbert, 1998, p. 123). Gilbert and Boulter (1998) have identified five modes of representation in expressed model; concrete mode, verbal mode, mathematical mode, visual mode, symbolic model and gesture mode of action. Cell concepts are usually presented using scale models (Harrison and Treagust, 2000; Coll and Taylor, 2005). Specially designed teaching models are used by the teachers to ease the process of conceptual understanding among learners, such teaching model varies between topics, and its development requires a process. Justi and Gilbert (1999) have identified eight models to study chemical kinetics, the idea based on energetics, catalysis and the reaction path.

The teacher has to be very cautious while developing or selecting a teaching model as a model can relate to some aspect not all properties of the target. There is a chance that a model may develop misunderstanding among the students through inclusion or deletion of any aspect which is not a part or parts of historical or consensus model respectively. Gilbert (1998) has identified attributes of valuable teaching model which a teacher should consult while using or developing a teaching model. A teaching model should relate to a consensus / historical model; which forms a significant part of the curriculum, related to any difficult concept for students to understand like double helix model of DNA, the source of the model should be familiar and acceptable to the pupils.

Gilbert further specifies good practices while using a consensus or teaching model. A good teacher identifies the main elements and relations within the model, identify the main elements in the source from which the model was developed. The teacher then goes on to establish analogy between the source and the model, using model to interpret the target, identifying the aspects which cannot be interpreted by the use of chosen model and evaluating the scope and limitations of the chosen model in explanation of the target (p. 164).

To this list Tregidgo and Ratcliffe (2000) stress that it is important the match any model with student ability, highlighting the similarities and differences between the target and the source to overcome building some misconcepts, while encouraging students to use the model in explaining scientific ideas and helping students to appreciate the strengths and limitations of models. Abell (1995) also warns that any model should be intelligible to the child's ability and meaning should be negotiated through the modeling process.

Design of Teaching: The Cell

This section discusses the teaching of the 'cell' content in science I course using a model and modeling strategy. The major aim was to enhance the content and pedagogical content knowledge of the five course participants who opted for science specialization in the MEd cohort of 2010. All the participants were experienced practising science teacher with different academic qualification. By the end of the unit 'Cell', it was hoped that student-teacher will drift away from the normal pattern followed by majority school teachers where they draw 2D diagramme on board or follow diagram given in the textbook and explain the attached text.

The whole teaching and learning process reported here was similar to Verhoeff, Waarlo, & Boersma, (2008) four elements of a system thinking competence to establish the effectiveness of model and modeling as content enhancing strategies in our context. It is suggested that students should construct and evaluate their own models to support their conceptual development (Coll and Taylor, 2005). The following sequences of strategies were followed; pre-test, time line, candy factory analogy, development of 2D model of cell, improving into 3D model of cell in the light of reflection and group feedback and lastly post test. Strategies, following learning pathway range from mental model to the construction of expressed scale model could be characterized as emergent modeling following Gravemeizer's (2002) concept.

We referred to two types of modeling activities:

(1) Referential activity, where students developed time line to exhibit the historical sequential growth of current cell knowledge and enacted candy factory analogy to build linkages between functions of factory units and cell organelles.

(2) General activity, where students developed 2D and 3D models of cells.

Modeling Strategy

Different modeling strategies were used to develop conceptual understanding of cell structure and function. Figure 1, entails a progression of conceptual understanding with distinct phases of knitting (thread in major discovering of cell organelles with reference to time), relating (building connections between functioning of factory units and cell organelles), building (developing 2D model), and rebuilding (reflecting and improving 2D into 3D model). All phases acknowledge the active participation of students in the physical process of modeling and development of mental model. Throughout the process, students were engaged in thinking back and forth between the mental model, expressed model and relating to the real cell. Two types of modelling activities (Gravemeizer's, 2002) were referred, referential (referring to something) and general activity (development of 2D and 3D model)

Modelling phase 1 (M1) referential activity. CPs developed the timeline to portray the evolution of current knowledge of cell. Student also played the role of renowned scientist in the landmark of cell history. This activity implicitly discussed the nature of science especially the tentative and evolutionary nature of science.

Modelling phase 2 (M2) referential activity. CPs modeled the candy factory analogy to understand the functioning of important units of a factory. CPs developed the mental model of factory units.

Modelling phase 3 (M3) general activity. Expansion of mental model. After some reading assignments CPs explained the structure and functions of the major organelles of a cell and discussed the functional detail of factory units and cell organelles. CPs developed the 2D model of cell.

Modelling phase 4 (M4) general activity. CPs reflected, discussed and improved the 2D model as 3D model of cell.

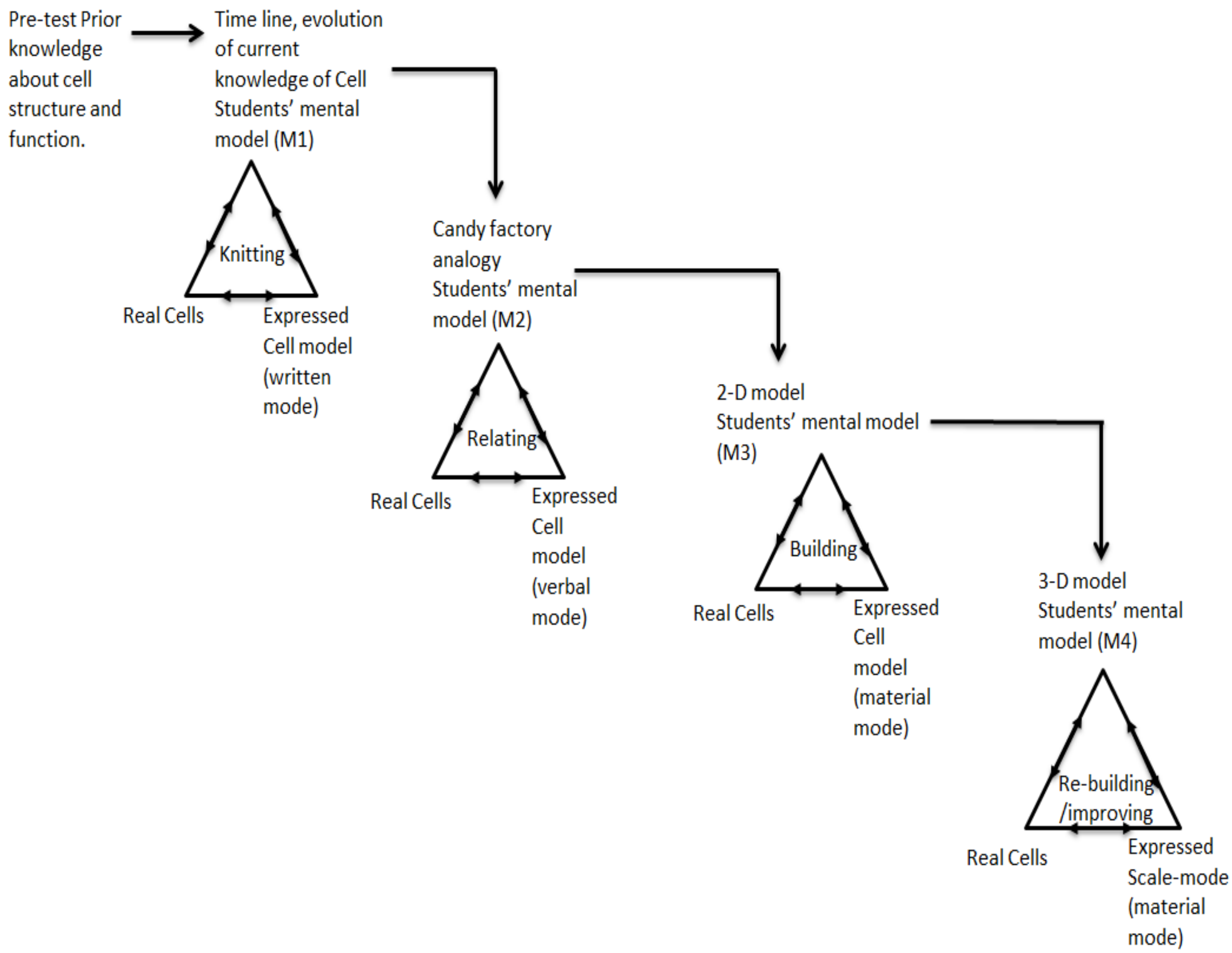

Figure 1: ***The learning trajectory from students' prior knowledge to the 3D model Adapted from Verhoeff, Waarlo and Boerma (2008)***

Modelling Phase 1: Time line

Electron microscopy has played a tremendous role in investigating and exploring the hidden sub-cellular details of a cell. Indeed, our understanding of cells has developed steadily with time and this dimension may be useful insight for the learners. This illustrates the way scientific knowledge is tentative and evolves with the passage of time. Often curricula and textbooks ignore the developmental phases of understandings of cells. As a result, students assume that such advance cellular knowledge has emerged in one attempt and do not appreciate the phases of development.

This activity was designed to include Nature of Science (NOS) and to pay tribute to the pioneers in cell research. A detailed text on history of cell biology was provided, from 17th century with the creation of first simple microscope, through through to 1931when Ruska invented electron microscope. In this regard, students-teachers were engaged in two activities.

Firstly, they developed a timeline showing different phases of development of cell knowledge from Hooke observing dead cork cells to the discovery of the electron microscope (Figure 2). Secondly, they performed role play. Each learner was given the role of one or more scientist. Students were also encouraged to use other sources of information to read more on the assigned scientist. They pretended to be the scientist assigned, highlighted their contribution with the date of discovery. They were also asked to present how they reached towards their discovery and how their contribution was different from other. Furthermore each scientist linked their work with previous scientist's work. They modelled the history of development of cell knowledge through expressed model as verbal mode and reported their findings by constructing a timeline as written mode showing the chronology of the historical events leading to the development of the electron microscope.

Overall, both activities helped them achieve two things; firstly, they understand gradual progression of cell knowledge from dead cork cell, to discovery of different cell organelles, to development of understandings of cells to the discovery of electron microscope. This can illustrate the tentative nature of scientific knowledge. Secondly, these activities also helped them understand that new knowledge emerges with the advancement of technology.

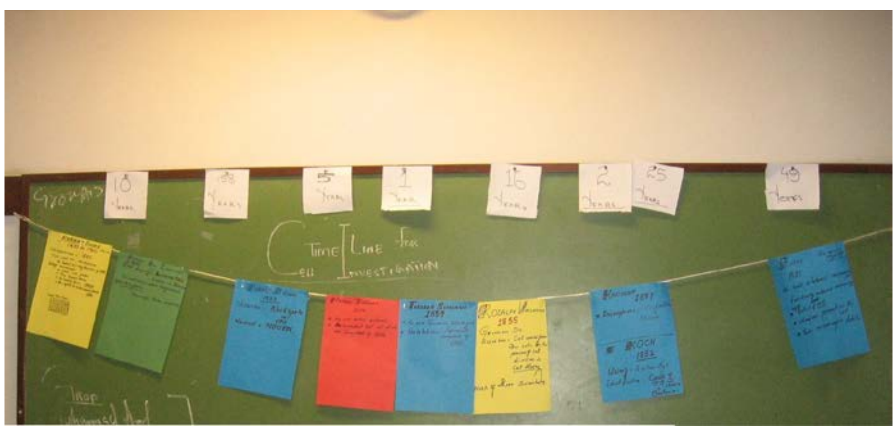

Figure 2: ***History of cell discovery-discovering through timeline***

Modelling Phase 2 (M2): Relate cell functions to candy factory working units (cell is functionally independent).

It is a known that the cell is functionally independent and every function performed at organizational level actually happens at cellular level. However, explaining to children how each organelle functions is a very demanding. Indeed, teachers find it difficult to help student visualize the sub-microscopic details of a cell. Crooke and Sheldon (2005) have argued that teaching the cell is difficult because students cannot see the cell with their own eyes. They disagree with the idea to start the topic with an exposure to the microscopic world. Their argument is based on the view that students can figure out only few details like nucleus, cell membrane and cell wall, sometimes chloroplast on a microscopic slide.

In this situation students get confused when teacher explain the complex processes like protein synthesis in ribosome, energy production in mitochondria and packaging at Golgi apparatus. Crooke and Sheldon have proposed to compare cell structure and function with something all students can relate to, like food. With this understanding, we used an analogy based on a candy factory (Crooke & Sheldon, 2005). We assumed that the comparison between factory units and cellular organelles will help develop better understanding related to the functions of important cellular organelles like Golgi bodies, nucleus, endoplasmic reticulum, ribosome, which are otherwise very difficult to explain. We designed candy factory on the floor as shown in Fig. 3.

We turned a large portion of the class into a factory (cell), in which student (organelles) modelled to produce, pack and deliver candy (protein). Factory floor plan serves as a visual reference. Factory zones were demarcated with ribbon, while each unit like president's office (nucleus), assembly line (ribosomes), packaging unit (golgi bodies), furnace (mitochondria), transporter (vacuole) of the factory were identified in the factory outline. Instructions were given to the students (factory workers) at the outset. Role play analogy followed by whole class discussion was carried out to relate target factory units to real cell organelle.

Figure 3: Floor Plan of the Candy Factory-Analogy for Cell

The purpose of the candy factory analogy was to introduce the function at more familiar and macro level. It was clear that each factory unit is independent in function but, at the same time, is interdependent and cannot work without other units. This analogy provided a reference that production of candy passes through different stages of production, packaging and delivery. Similarly, in cell each organelle performs its own function to produce, modify, pack and deliver protein at any specific site. This activity helped understand organelles functioning to something more familiar and meaningful to *them and they can relate* cell functioning with factory jobs. Therefore transition from factory to cell was smooth while discussing and comparing the both i. e factory and cell.

Modelling Phase 3 (M2): Developing a general 2D model of cell (Cell structure)

Based on learning (the mental model they developed) in the first two phases and labeled diagram provided, students developed a 2D model. Gilbert and Boulter (1998) argue that learners be given explicit opportunities to become aware of their mental model and to share these with the models presented by others. Relevant materials for developing models were provided. Figure 4 presents an example of some organelles developed by the participants. They arranged these diagrams on soft board to present 2D look of a cell. The 2D model developed was an interpretation of their mental model and what they observed in the 2D diagrams provided (elaborated much simplified diagrams provided a clear picture of cell and cell organelles). In the feedback session facilitator and the participants discussed the structure of each organelle in the 2D model and compared with the micrograph. It was also discussed how a particular shape facilitates the functioning of the organelles. Interconnections between the organelles were also highlighted. Students also revisited the text and highlighted the key structural feature missing in the 2D model. The outcome of this discussion was to improve 2D and build it as 3D model so that each organelle can get its proper place and appropriate shape in a cell, a very important aspect in a scale model.

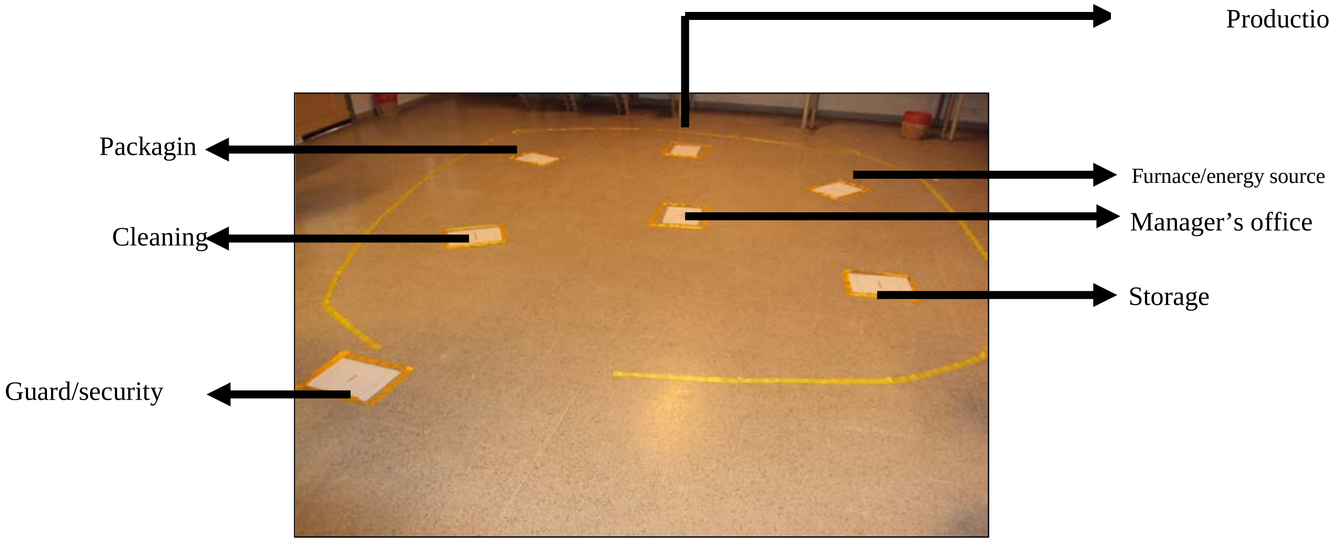

Figure 3: ***Floor plan of the candy factory- analogy for cell***

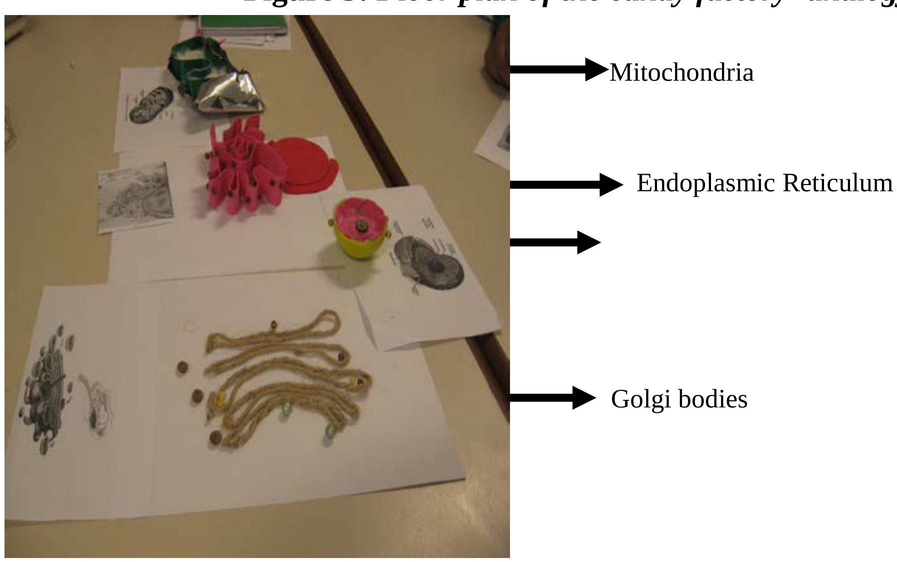

Figure 4: ***Developing Cell Organelles for 2D Model***

Modelling Phase 4 (M4): 3D Model of cell

Building the 3D model was based on the assumption that it would enable students to visualize better the relationship between different organelles as compared to 2D model. The rationale to introduce 3D model at this point is based on the fact that 3D modeling is found to facilitate cognitive development and the modelers are less likely to develop misconceptions and can use new and specialist terminology frequently (Tregidgo and Ratcliffe, 2000).

In the light of the feedback, discussion and self-reflection over 2D models, students developed a 3D model of animal cell. Electron micrographs were the key to help in developing a model close to structure proposed by the scientists. In this connection the complexity of electron micrograph was minimized by using simplified photograph with clear structural details of each organelle. Students worked in their respective pairs to build a 3D model of certain cell organelle which were later on placed in a large 3D model of cell. Students discussed the microscopic structure of each organelle, their position at sub-cellular and cellular level, functions they perform and the inter linkages between the organelles.

Assembly of the organelles generated rich discussion. They discussed what should be the position of the organelles, how the position of an organelle could facilitate the working, how one organelle facilitates the working of other organelles? It was beautiful to note the learning moments, the knowledge rich discussions. Discussion also revealed the importance of the model as an effective tool by giving visual representation of a structures that cannot be seen directly. Students also acknowledged the model as a way to reduce the complexities portrayed by electron microscope photographs. They further discussed the effective use of 3D model and modelling process in the classroom, students and teachers role while developing models.

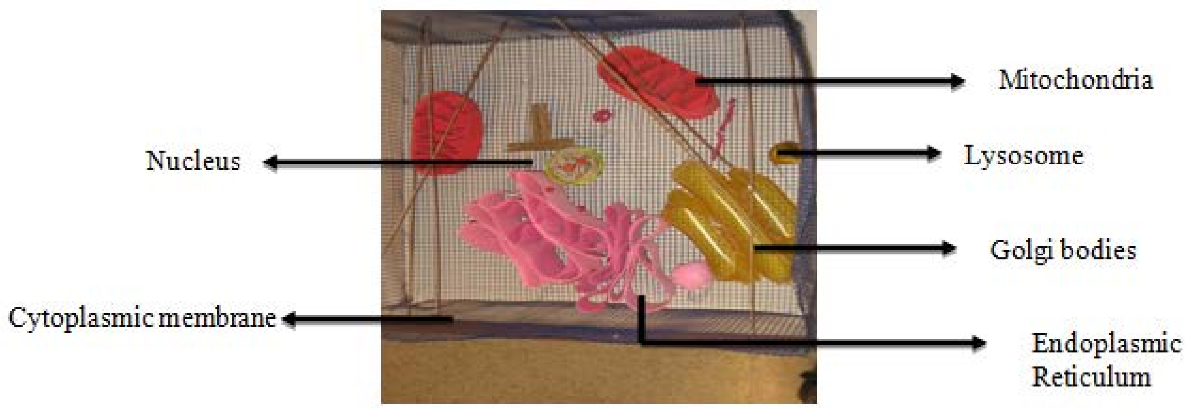

Figure 5: ***The learning trajectory from students' prior knowledge to the 3D model***

Students also built relationships between organelles by trying to move hypothetical molecules from ribosome (protein produced) to endoplasmic reticulum (protein modified) to Golgi apparatus (protein packed) till exocytosis (protein excreted out of cell). During such presentation and discussion students' tried to attain better understanding of the structure and nature of relationship between organelles.

At the end of all four modeling phases, students realized the potential of using model and modeling as an effective teaching and learning strategies. They also acknowledged the multiple uses of model i.e a thinking tool that can be purposefully manipulated by the modeller to understand the concept (Parkinson, 2004).

Gauging the content knowledge of CP through Pre-Post test strategy

A facilitator-developed test was administered before and after teaching concept of 'structure and function of cell. The purpose of pre- and post tests was to gauge the difference in content knowledge before and after teaching an abstract concept: cell. Pre-test also helped facilitators tune their planning to address the needs of CPs. Test consisted of 15 items including Multiple Choice Questions

(MCQs=5); fill in the blanks (Blanks =5) and Constructed Response Questions (CRQ=5). An answer key was developed before marking paper for consistency. For all three categories correct answers were coded as 1 while incorrect were coded as 0. However, for CRQs an additional category of 0.5/0.25 marks were allocated for partially correct responses. Figure 1 shows a comparative overview of overall pre-post results. While degree of improvement differs from case to case, it is evident that all CPs have made considerable improvement.

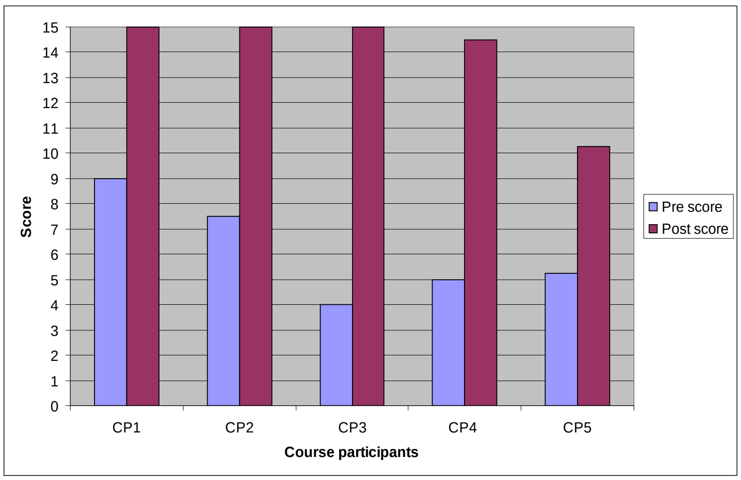

Figure 6: ***Pre-post test scores: Overall comparisons***

A detailed analysis was carried out at category level. Figure 7 demonstrates that results followed a similar pattern.

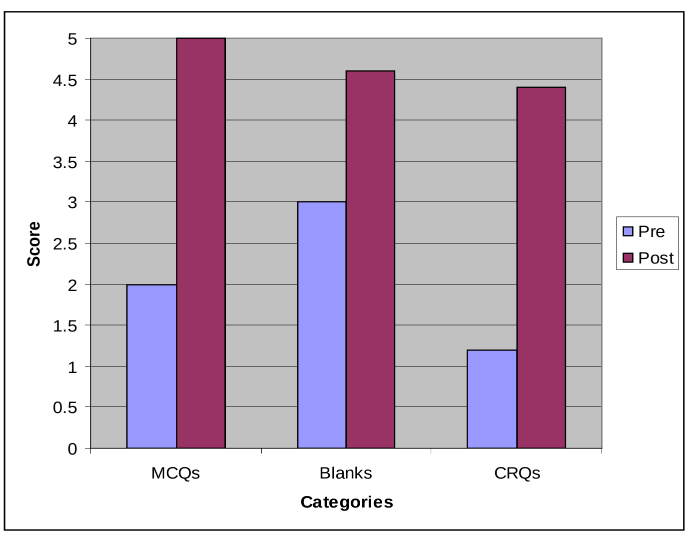

Figure 7: ***Pre-post test scores - comparisons at category level***

While all CPs have responded to all MCQs correctly in the post test, the pre-post difference is comparatively bigger in CRQs as compared to the other two categories. It was encouraging to observe that CPs have made substantial improvement in CRQ where questions such as "Why plasma membrane is called semi permeable membrane?" and "Describe and draw the structure of rough endoplasmic reticulum?" required more thinking and comprehensive knowledge to 'construct' responses. According to them they found this part the most difficult one during pre-test. Some of the facilitating factors identified by the CPs in improving overall score in general and CRQs score in particular were strategies which helped them to move from simple to complex. They specifically mentioned that analogy, construction of 2D and 3D models, assigned reading and discussions have helped them to learn an abstract concept. The results were shared with CPs through visual graphics (figure 1) to help them see 'where they were'; where they are' and 'how much improvement is required'.

Conclusion

Teaching unit 'the cell' was designed on four modeling strategies towards acquiring coherent understanding of structure and functional knowledge of cell and exposing students-teachers towards different pedagogies to teach cell in their classrooms. All distinct modeling phases were proved to be powerful strategies to visualizing cell concept. This was evident through better post test result, group discussion, outcome of each phase (developed timeline, factory role play, content rich group, 2D and 3D scale models). Each modeling phase was recognized worthwhile in relating and understanding cell structure and function. Whereas, 3D modeling phase (M4) was the most helpful for enabling students visualize abstract scientific content which could otherwise remain difficult to understand. 3D modeling is a time consuming process, but it help in better understanding with comparatively less time. It is hoped that the understanding gained will help students in relating cellular structure and processes to higher level of organization.

Students found model and modeling as effective tool by giving visual representation of cells and the difficult concepts related to the functioning of cells. Students also acknowledged model as a way to reduce the complexities portrayed by electron microscope and effective use can help teachers to explain the complex phenomenon in the classroom. It is hoped that student-teachers have gained new understanding about the nature of model and modeling. They have experienced model as a thinking tool and it is always good to represent the situation by a number of different models. Knowing that, model is a powerful learning tool but if used inappropriately could generate a number of misconceptions.

This paper recommends teacher education programmes to engage students-teachers in purposeful modeling activities as a vehicle to understand modeling as an effective pedagogy and a means to enhance content knowledge.

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