Models and Modeling Behavior: A Look at the Critical Thinking Skills of Biology Majors

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Abstract: This paper describes the types of models that biology majors use and how they go about making their models in learning key concepts in biology such as the cell membrane, cytoskeleton and cell structure. Initially, a total of 44 biology students from all year levels enrolled in the second semester of calendar year 2008-2009 were asked to make their respective models of the cell membrane, cytoskeleton and cell structure. They were also asked to answer an open-ended questionnaire. Of the 44, only 20 (five from each year level) were randomly selected for a one-on-one interview. Results showed that the student-generated models from all year levels were mostly analogies, some textbook definitions and occasional drawings. In making their model, students first read the text; second, outline similarities in structure and function or both; and third, make the model. Data suggest that models are good diagnostic tools for identifying critical thinking skills of students. In this case, students mostly demonstrate the ability to recognize similarities in structure and function between the concept and their model. Some senior students demonstrated integration and reflective thinking in making their models. Thus, more opportunities for student-generated models must be available if students were to develop integration and reflective thinking in their models.

Key words: Models, modeling, critical thinking

Introduction

While there can be no one definition of critical thinking, some basic competencies include problem recognition, problem solving, data interpretation, synthesis, drawing conclusions and evaluation (Glaser, 1941 cited in Fisher, 2001). Dewey called critical thinking as reflective thinking and saw scientific thinking as a model of reflective thinking (Fisher, 2001).

The use of models and modeling in science teaching fosters critical thinking development. With models students can think critically and creatively (Finster, 1991 and Perry 1970 cited in Harrison and Treagust, 1998). With modeling or model making students become more engaged and thus, enhance their critical thinking skills (Saiki, 2007). Saiki (2007) in her earlier work (2005) describes a modeling activity developed in a university course in costume history. In the study, students were grouped into two or three persons. The students were to make bustle shapes to represent three key periods. Students were then to present their work and vote for the most accurate and the most creative made skirt model. This part of the activity involved critical thinking skills and strengthened course information (Saiki, 2007).

Models are central to analogical reasoning, model-based reasoning, and problem-solving and are keys to summarizing data, making predictions, justifying outcomes and facilitating communication in science (Erduran and Duschl, 2004).

In an earlier paper, Harrison and Treagust (1998) describe models as both implicit and explicit. Implicit models represent functions, variables, particles and processes and are part of the language of science. Explicit models often use concept-building analogical models to include scale models, pedagogical analogical models, maps and diagrams, and simulation to represent objects, ideas and processes (Harrison and Treagust, 1998; Gilbert and Boulter, 1998).

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In their study, Harrison and Treagust (1998) surveyed 48 Australian science students attending three different schools (a prestigious girls' college, a large city high school and a rural high school). They observed that models range from concrete scale models that depict no more than superficial features to abstract concept-process models using multiple models to represent scientific processes. They suggest the need for teachers to gradually challenge students to use more abstract and difficult models to increase student modeling skills.

The literature on the use of models and modeling in science teaching point to the following: first the revisionary nature of models (Hodgson & Harpster (1997), Harrison & Treagust, 1998) second the furtherance of critical thinking development and creativity in students by modeling activities (Chang, 2007, Yost & Gonzalez, 2008), and fourth the facility of some elements of student reasoning like the consideration of multiple viewpoints, synthesis of new ideas, and application and integration of knowledge as evidenced in the active conversation by students (Yost & Gonzalez, 2008).

Thus, this paper explores the types of models biology majors use including their modeling behavior (model making) in learning key concepts in biology such as the cell membrane, cytoskeleton, and cell structure in general.

As biology majors, a good grasp of the cell membrane, cytoskeleton and cell structure is crucial in understanding cell and molecular biology, vertebrate embryology, comparative anatomy and anatomy and physiology to name a few. For example, cell-cell adhesion along with cell-cell communication, signal calling and induction are some of the basic processes in vertebrate embryology that require the ability of students to recognize structure and function relationship in cell membranes and the mechanism involved therein. In addition, the importance of the cell membrane and cytoskeleton in maintaining cell integrity and cell migration are critical in recognizing the implications a dysfunctional cytoskeleton will have on the cells and on the organism. To cite, cells that have lost the ability for cell adhesion results from a dysfunctional cell membrane and cytoskeleton along with the inability of the cells to recognize 'checkpoints' in the cell cycle. Finally, recognizing structure and function relationship of cell structure is key to understanding the pathology of certain diseases like cancer, or understanding attempts at treating the same at the molecular level in molecular medicine. Therefore, in this study, biology majors were supposed to show the foregoing critical thinking skills in their models and modeling (model making) of the cell membrane, cytoskeleton and cell structure.

The foci of this study were to 1. Recognize the model/s that biology students use. 2. Describe the modeling behavior of students and to 3. Determine the critical thinking skills students show based on their model making. In this study, models represent an idea, an object, an event, a process or a system as defined by Gilbert and Boulter (1998). Modeling refers to the model making activity of biology majors.

Thus the working framework of this study lies in the two-way relationships among models, modeling and critical thinking (Figure 1). Through model making activities students become more engaged and aware of their own learning; both of which enhance critical thinking skills. Thus the critical thinking skills will be evident in the type of student-generated models from modeling or model making.

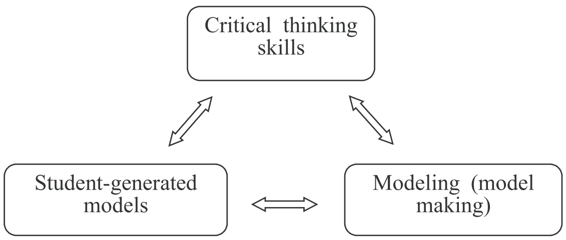

Fig. 1 *Student-generated models and Critical thinking*

The significance of this paper then is two-fold. First, having biology majors recognize the models they use and describe their modeling behavior makes them aware of the ways they explain and understand concepts. Second, recognizing biology majors' models including their modeling behavior will help teachers determine the critical thinking skills students demonstrate. Efforts at improving pedagogy among biology teachers will have been based on the context of students, just as what constructivist framework emphasizes in several literature.

Method

1. Research Design

This study was designed to explore the types of models and describe the modeling behavior of biology majors. Initially, the participants were asked to make models of the cell membrane, cytoskeleton and cell structure to determine the type of model they use. Although not part of the research objectives, they were also surveyed on their basic understanding of the terms models and modeling in the science classroom using an open-ended questionnaire. Since this is a preliminary work in the department, the author thinks this will be useful information as well. To determine the modeling behavior of the students, one-on-one interviews with randomly selected biology students formed the final phase of this study.

The foregoing basic concepts were chosen since all three are critical in understanding cell and molecular biology, vertebrate embryology and comparative anatomy. If students were found to demonstrate faulty models, this could be useful diagnostic information for remedial purposes. The model making activity will be informative in terms of identifying the critical thinking skills demonstrated by the participants.

2. Sampling Design

The participants were students enrolled in the Bachelor of Science in Biology. For School Year 2008-2009, there were 44 students enrolled from all year levels. Initially, all 44 were asked to make models of the cell membrane, cytoskeleton and cell structure. There were 13 first year, 5 second year, 9 third year and 17 fourth year students.

Five regular (those who did not have to repeat any one of the subjects in the curriculum) biology students from each year level were randomly selected for the interview phase of the study. Those who were absent during the model making activity were no longer considered in the random selection of interviewees.

3. Research Instrument

An open-ended survey questionnaire was used to determine biology students understanding of the terms models and modeling in the science classroom, frequency of use of models and the type/s of model/s they use as part of facilitating their learning. The survey questionnaire contains 9 open-ended questions.

The survey questionnaire does not answer any of the research objectives. However, since this study is a preliminary work in the department, the author thinks that information about the participants' understanding of the terms models and modeling in science classroom are useful baseline information. Below are the questions in the survey questionnaire.

1. What are models in the science classroom?
2. Give examples of models that your teachers in Biology use in the science classroom.
3. How often do your Biology teachers use models in the classroom?
4. Which of the models used by your Biology teachers facilitate your understanding of science concepts?
5. Which models do you use when studying science concepts? (Name as many as you can)
6. How often do you use models? Why?

7. Which of the models you use help you understand science concepts?
8. What is the importance of modeling in the science classroom?
9. Are models and modeling (as used in the science classroom) the same?

3. Data Gathering Procedure

Students from the different year levels were scheduled on separate occasions, depending on their free time. The scheduling was done earlier and in consultation with the students. So for the model making activity and conduct of survey questionnaire, four schedules were arranged for the year levels.

For the interview, only five biology students from each year level were randomly selected. Students who were absent during the conduct of the survey and modeling activity were excluded from the selection process for the interview. Since the interview aimed to answer the objective on modeling behavior, the author thinks that randomly selecting 5 students to represent each year level was enough. Since the group was homogenous, bias in terms of selecting between good and ill-performing students was avoided.

4. Data Analysis

To determine the type of model a student used, the author adopted the typology of concept-building analogical models by Harrison and Treagust (1998).

The modeling behavior of students was described based on the common activities students did when making their model as mentioned in the interview. From the interview transcripts, the critical thinking skills of the students were measured in terms of the following abilities: recognition of structure-function relationships, integration, reflection, draw implications and explanation of their model.

Results and Discussion

Research on student-generated models and modeling activity is pivotal in fostering critical thinking development. While it was not the focus of this study to determine how biology majors understand the terms model and modeling, it was important to resolve such at the start. Table 1 outlines the biology majors' understanding of the terms model and modeling as was evident in the survey questionnaire.

In general, students look at models as something tangible, subject to manipulation (something that can be handled or touched) and could range in form – from symbols, pictures, objects, products, materials or things, and figure to live organisms. In an interview, one student claimed that '*models have a subjective element in them*.' Another student said '*models give students a sense of personality; as they reflect students' way of thinking*.'

According to Flávia, Ferreira and Justi (2007), model making entails choosing and integrating issues that are assumed to be relevant for a specific question. This is where the importance of knowing the meaning of 'model' is pivotal. Flávia, Ferreira and Justi (2007) further said that in science education, it is imperative that students have some initial knowledge about what models are including their use and limitations if we want students to engage in modeling activities.

To recognize what students understand of the term modeling is just as significant in this study. Students consider modeling as a process; an activity where they are to picture out, represent, show, describe, explain, make, draw or portray something (Table 1). The foregoing descriptions point to a very important feature of modeling activities – the active participation of students in the learning process. Here, students create their own answers and build meaningful relationships through their experiences. In an interview, one student said: '*models reflect what I usually think of, what I usually get in contact with, things I understand most – it is experiential*.'

Table 1

Biology majors' understanding of the terms model and modeling

Year Level	Model	Modeling
First Year	Shows other people; a figure; can be anything;	To picture out - do something to show to people; is a description, an explanation; making representations;
Second Year	Gives life to something; represents something; a symbol or representation of certain things; representation; something that you see;	The act; clay modeling; when you are going to represent something; process of representing; when you make something;
Third Year	A noun - the object; is the structure; represents a certain structure; a substitute to explain; representative for a certain thing;	the action or the ways on how to show that model; process of making a model; showcases something; is a human activity - a process; represent something in simpler things;
Fourth Year	Tends to be subjective; the object, the product; refers to materials; things;	Having a concrete example; tends to be objective; the process; refers to an activity; drawing out a concept or action; something you want to portray;

Table 2 summarizes the types of models biology majors used as shown in their modeling activity.

Based on the model making activity, the student-generated models from all year levels mainly consist of analogies, some textbook definitions and occasional drawings (Table 2). Students were familiar with a wide range of models though. Some excerpts from the interviews explain why most students used analogies in combination with drawings in making models. One student said, '*I thought of making some analogies because it was easy for me to represent each*'. Also, she said, '*I haven't exerted much effort, because what I did was just recall what we did last time* (in reference to a similar activity in one of her classes). *So it was just easy for me to come up with those things*'. Likewise, another student said "*analogies are more effective for me because they came from us*".

Table 2

Types of Models that Biology majors use

Year Level	Student-Generated Models	Other Models [that students are familiar with, or they have been exposed to in their other classes]
First Year	Mostly analogies (8 out of 12), textbook description (3 out of 12), 1 was absent	Drawing, concept map, pictures, scale models (animal organs, plant organs, skeletal system, muscular system), graph, table, live organisms (frog dissection)
Second Year	Mostly analogies (3 out of 5), drawing (1 out of 5), 1 was absent	Drawings, scale models (animal organs, plant organs, skeletal system, muscular system)
Third Year	Mostly analogies (7 out of 11), textbook description (3 out of 11),	Symbols, scale models (planetary system, animal organs, plant organs), clay models, drawings
Fourth Year	Mostly analogies (5 out of six), drawing	Concept map, drawings, clay model, scale models (animal organs, plant organs, skeletal system, muscular system),

In the actual model making activity, one student used the skin, spring bed and macaroni salad to represent the cell membrane, cytoskeleton and cell structure respectively (Figure 2). In the interview, when asked how she made her analogies, she said "*I was trying to relate the drawing with the function of the cell membrane*" (in reference to the skin analogy). "*For the cytoskeleton, I thought of the spring bed since like the cytoskeleton, it serves as the framework and is flexible in character*". '*With the cell structure, I thought of a thing that is made up of different things inside; just like the macaroni salad* '. In her modeling document, she further said that "*the skin plays similar role as the cell membrane*. "*Primarily it is for secretion, protection and absorption*". "*A bowl of macaroni and cell structure are somehow alike in a way that each contains a specific ingredient/structure that has a specific function to be able to make the entire thing work*". Here, the student considered the function, property and composition of her analogies in establishing similarities with the concepts she modeled.

Another student described his analogies of the cell membrane, cytoskeleton and cell structure. According to him (in his modeling document), "*one can relate the cell membrane with an ordinary concrete wall*". "*Such wall containing gates and doors for entrance may resemble a membrane equipped with various protein pumps that allow selective transport of compounds*". "*Reinforced concrete wall also resembles such membrane because just like the cell membrane, reinforced steel is sandwiched between two concrete layers*". "*The cytoskeleton can be related to an actual framework of a building*". "*It is of different sizes, strength and flexibility according to one's function*". "*Similarly the cytoskeleton composes different filaments as the thin, thick filaments and microtubules*". "*Both provide structural support flexibility and even movement*". "*Cables not only strengthen building and hold objects, as seen in the cables of an elevator (this is similar to the work of the microtubules during mitosis)*". "*One can relate the cell structure with the everyday different things*". He continues by citing the generator works like the mitochondria being the powerhouse of the cell.

Flávia, Ferreira and Justi (2007) stress that 'a model of a *target*, that which is to be represented is created from a *source*, some other object, event or idea by the use of metaphor in which the target is seen, if only initially for the sake of argument and for a short time, as being very similar to the source'. Truly, this was evident in most student-generated analogies; except, for occasional analogies whose target and source conflict (Figure 3).

The student who used a house (Figure 3) for his analogy of the cell membrane, cytoskeleton and cell structure failed to show how the different parts of the house represent the foregoing concepts. This is how he attempted to describe his model: "*The cell structure describes how complex the cell is*". "*It somewhat plays different functions to maintain balance and*

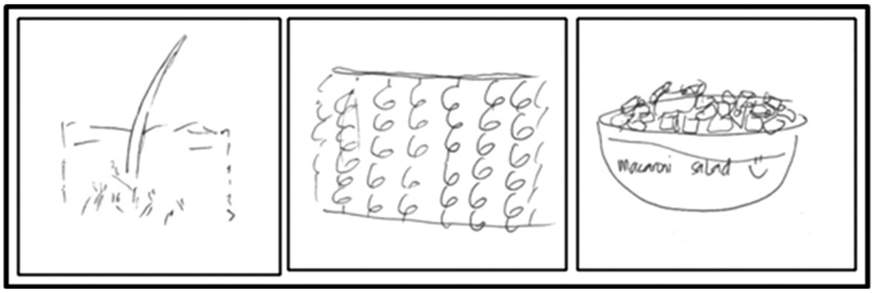

Fig. 2 *Sample model from a fourth year biology student*

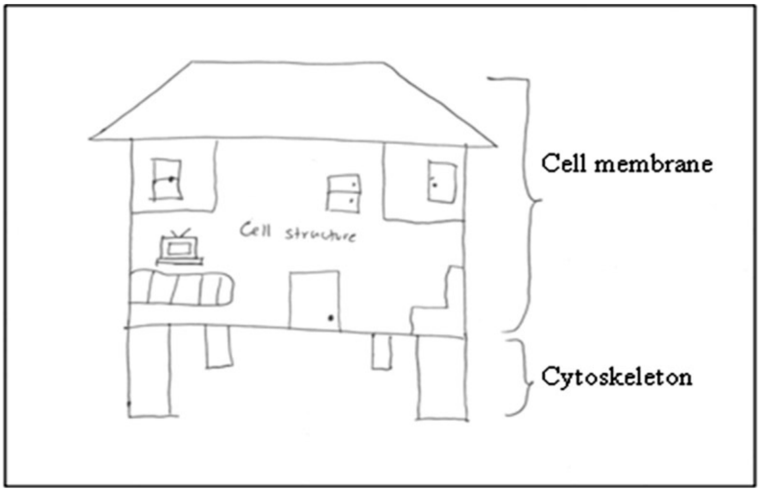

Fig. 3 *Sample model from a second year biology student*

homeostasis". The student's description here is incomplete as he did not describe further what makes the house an analogy for the cell structure. According to him, *"the function of cell membrane is like a skin, which provides protection from the external environment"*. However, his analogy (Figure 3) refers to the walls of the house as the cell membrane. In this case, the target (concept) and the source (model) are in conflict. He further described in his modeling document that the cytoskeleton *"serves as an attachment to the extracellular matrix and that the cytoskeleton provides shape to the cell"*. However, in the interview, he explained his model. According to him *"inside the house are several structures; example light and appliances which are the cell structures. "The wall represents the membrane which protects the house from bad elements". "The stand is the foundation of the house"*.

Analogies are common and widely studied. To cite, Coll and Treagust (2002) investigated the use of analogy to facilitate secondary school, undergraduate and postgraduate students. The results showed that students make use of analogy to facilitate their explanations of chemical bonding. In like manner, for most biology students in this study, analogies were common (Table 2).

The analogies in this study were mostly shown in the forms of drawings, text or a combination of both. For students who drew to show their analogies, some used one drawing to represent all three concepts. For example, in an interview, one fourth year student said: *"It was easier for me to have it that way. At least there's one object in focus at the same time. I would be able to look for the connections and relationships of the 3 structures in one object'*. She continued, *'It's hard to have them separate. "How can I see the relationship among the 3 when in fact, their relationship lies in the relationship they have during cell processes"?* She used a building as her model of the cell membrane, cytoskeleton and cell structure (Figure 4).

While most of her classmates and other biology students used similarities in function, structure and composition as bases for their analogies, it is notable that hers went further by drawing connections and relationships of the three concepts in one object. Her ability to see the relationship of the three possibly stems from an extensive background she amassed through the years from her majors like cell and molecular biology and vertebrate embryology.

Likewise figures 5 and 6 are examples of

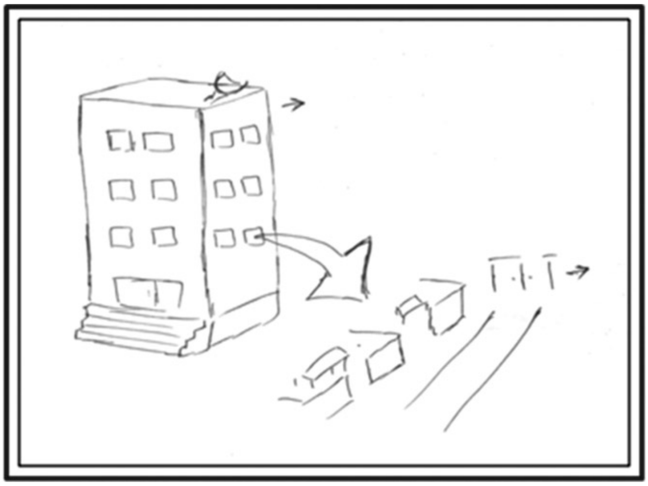

Fig. 4 *Sample model from a fourth year biology student*

analogies represented in one drawing by a fourth year and second year student respectively.

In figure 5, the student used the cell model itself to show the cell membrane, cytoskeleton and cell structure. The student recognizes that all three concepts are related to the cell. The drawing is commonly found in science textbooks. According to the student, *"at times it is hard to imagine and concrete models facilitate learning better"* (Figure 5).

In figure 6, the student compares the cell membrane, cytoskeleton and cell structure to a human body. She explained why in her modeling document. According to her, *"in order for the body to function well and effectively each part must do its job". "Each part has different function with different use". "In terms of morphology, the body cannot and will not be straight upward without a skeleton, which is the supporter and protector". "It is the same with the cell structure; each part has different function and cooperates with one another in order for the cell to work properly". If one part is missing, definitely the cell will not work*

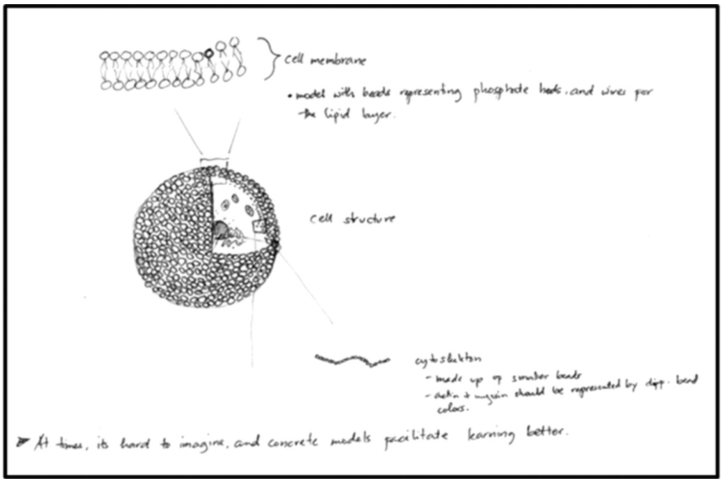

Fig. 5 *Sample model from a fourth year biology student*

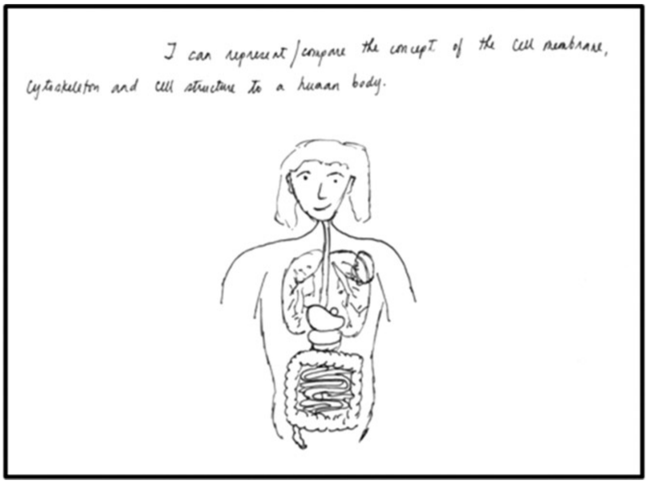

Fig. 6 *Sample model from a second year biology student*

properly". Here, the student also recognizes the relationship of the cell membrane, cytoskeleton and cell structure as parts of a cell. She further recognizes the importance of the function of each and how the other parts will be affected should any one part be missing as she compared and likened the cell parts to a human body.

In another model, one third year biology student drew a school to show the cell membrane, cytoskeleton and cell structure combined (Figure 7). She compared the gates (G1, G2, G3, G4 & G5 in figure 7) to the cell membrane whose function is to selectively allow certain materials in and out of the cell; whereas in the school analogy, the gates will only allow the students officially enrolled and the school's employees. She compared the cell structure (cell parts) with the different members of the school like the administration, the teachers, students and staff. She compared the cytoskeleton with the buildings and rooms where students and teachers have their formal and social interactions.

Conversely, biology students from the lower years (first and second year), had simple and superficial treatment of their analogies. When probed further, there was little if no information

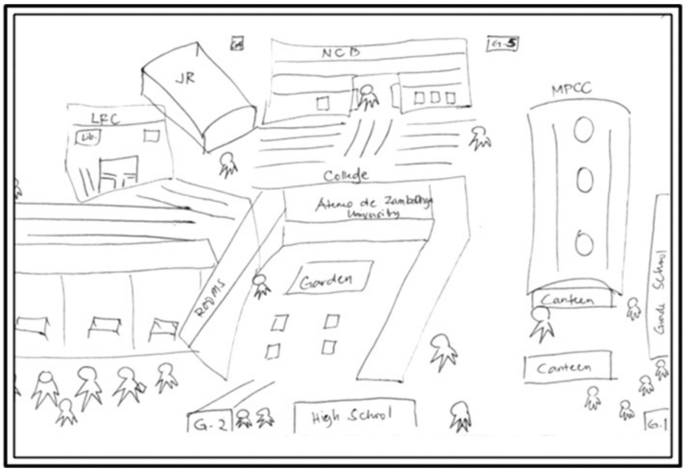

Fig. 7 *Sample model from a third year biology student*

offered. In the interview, some of their common replies were: '*I am not sure*' and '*I don't know*'. Figures 8, 9 and 10 are modeling documents from first year students and a second year student respectively.

In the interview, the student when asked why she described her analogy in text form (Figure 8) rather than drawing, said that she had a hard time drawing. She further said that although her analogy is not exact, she believes her watermelon analogy is similar to the concepts it was supposed to represent. Whereas, the

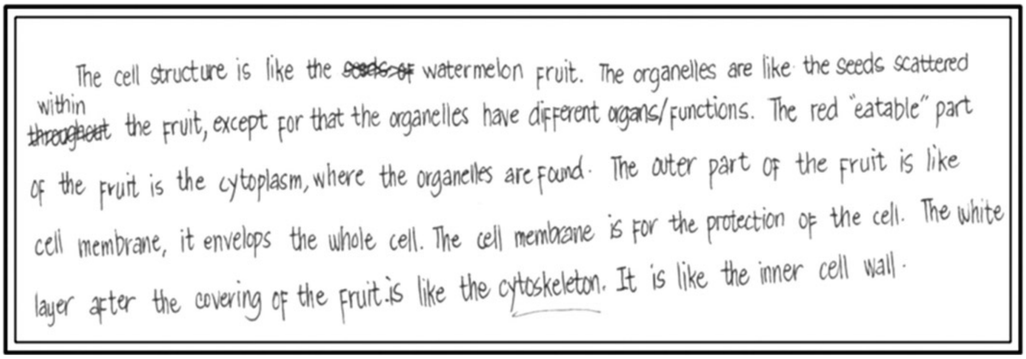
The cell structure is like the ~~seeds of~~ watermelon fruit. The organelles are like the seeds scattered ~~throughout~~ within the fruit, except for that the organelles have different organs/functions. The red "eatable" part of the fruit is the cytoplasm, where the organelles are found. The outer part of the fruit is like cell membrane, it envelops the whole cell. The cell membrane is for the protection of the cell. The white layer after the covering of the fruit is like the cytoskeleton. It is like the inner cell wall.

Fig. 8 *Sample model from a first year biology student*

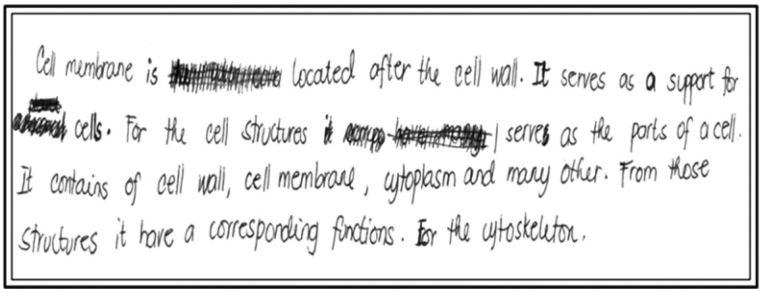
Cell membrane is located after the cell wall. It serves as a support for cells. For the cell structures it serves as the parts of a cell. It contains of cell wall, cell membrane, cytoplasm and many other. From those Structures it have a corresponding functions. For the cytoskeleton.

Fig. 9 *Sample model from a first year biology student*

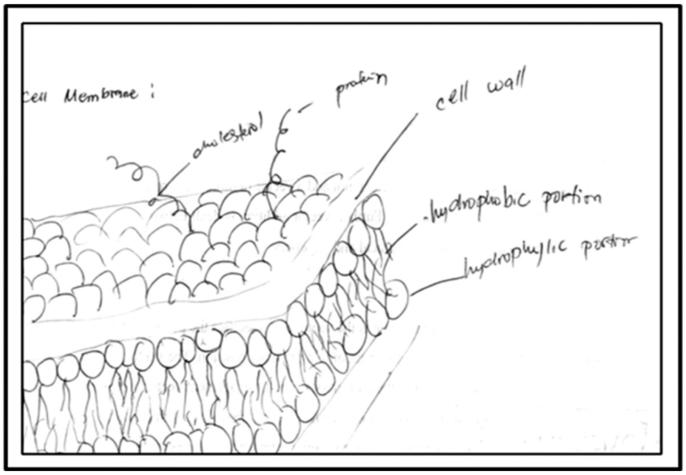

Fig. 10 *Sample model from a second year biology student*

student's description in figure 9 is not an analogy as she simply described the cell membrane, cytoskeleton and cell structure following textbook definitions. Yet her descriptions were incomplete. For the student who drew figure 10, she used society as her analogy; in addition to making a drawing of the cell membrane. According to her, the nucleus, mitochondria, cytoplasm, Golgi bodies, cell membrane and lysosomes are like the President, Department of Energy, Philippines, Department of Trade and Industry, police and water district respectively. Because she forgot the function of the lysosome, she thought it stores water that is why she compared it to a water district. In actuality, the lysosome contains hydrolytic enzymes whose function is to digest worn out parts of the cell or destroy any invading material that happens to enter the cell.

All the foregoing sample models suggest an element of careful consideration of similarities between the target and source, which is a cognitive process. According to Flávia, Ferreira and Justi (2007), modeling 'is a cognitive process of producing and modifying mental models'. Furthermore, when modifying something, a person finds expression of such models in different modes of representation.

Of the 20 students interviewed, 8 claimed that in the process of making their respective models, they had to review, change and or choose the best model to fit the concepts they were asked to model. This was evident in the following excerpts: *"I would review and sort as to which model has more similarities or which one better fits the concept". "I would come up with different things and then choose the best". "I would be careful on how to represent; I even doubt or check my work". "It took a while for me as I did not want to jump to a model that I was not sure", I was thinking of the best model I can use for all structures". "I review the correctness of the representation".*

Figure 11 describes the modeling behavior of biology students when asked regarding how they made their respective models. This synthesis was based on the students response to a question on "how they went about making their model" during the interview. Furthermore, the synthesis in figure 8 was mostly based on the descriptions of the fourth year students and some third year students as they were more elaborate and quite conversant during the interview.

The modeling behavior of biology students (who were interviewed) consists of text reading or memory recall, outlining of similarities in

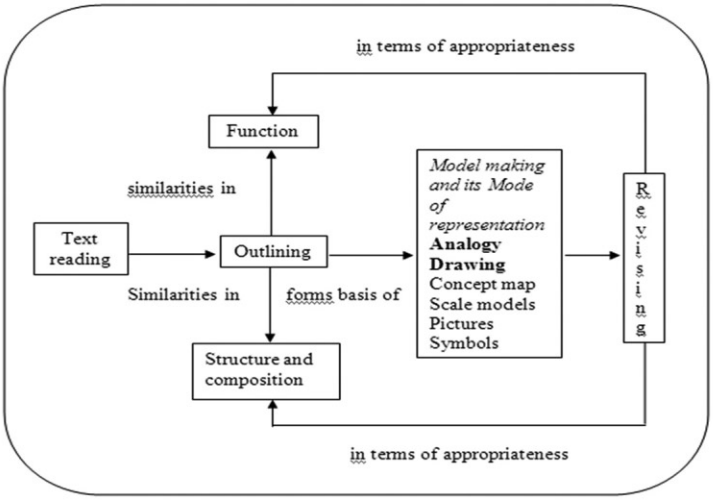

Fig. 11 *Biology majors' modeling behavior*

function, structure and composition or both, making the model and revising the model which means reviewing and modifying their models whenever appropriate. In the interview, several students claimed that they review the appropriateness of the model in representing the concept based on the proximity it shares with the concept in terms of function, structure and composition. For example, one student said '*My model went through many changes. I don't want to easily jump to a model that I am not sure. I was thinking of the best model I can use for cell structure. It takes a while for me to think about it.*' Another student said '*Prior to my final output, I have many examples, and then I would choose only one. It is like sorting them as to which one has more similarities and which one would better fit, then I would compare*'.

The following narratives came from four fourth year students and two third year students who were each asked to describe how they made their respective models.

Student 1: '*First I read the materials, then I try to recall the important details, and then I write things that are easy to remember, then from that, if it can be drawn, I'll draw it. If not, I just do my concept map.*

Student 2: '*First, I will look at the properties of the concept or the things that I am about to be modeling. For example, the membrane, what are the things that make up the membrane, its components, structure and everything? After that, I am not only thinking of a particular object, but it may be a system or a group of objects that would best represent the cell membrane. By making that I will be linking similarities and how they function.*

Student 3: "*I brainstorm the best model then choose one model; and if there are certain structures or functions that the model cannot totally illustrate, so I will find another one that will be better than the first one; or come up with different things and then choose the best*".

Student 4: "*I think of similarities and the linkage. I think of an object that can portray the concept or the properties of cell structures. I think how the function of the analogy can be incorporated to the function of a cell membrane. My model went through many changes since I did not want to jump to a model that I am not sure*".

Student 5: "*One has to be familiar with the function, go on with describing the object I think is similar in function with the concept, and then review for correctness of the representation*".

Student 6: "*I think of the concept, its function and structure, I then make the analogy, review it (at times) then improve my work*".

Among the students who were interviewed, the fourth year students were more elaborate and certain in describing the process of making their respective models. Their confidence possibly results from more experience and extensive background compared to the lower years, particularly the first and second year students. By this time, the fourth year students already developed integration and reflective thinking. They are more aware of their own thought process and demonstrate a sense of ownership, a sense of the 'self' in their output. This is evident in the following lines: '*With models, everyone is given a chance to make their own models sense of personality; models reflect students' ways of thinking*'. *Models are part of knowing the self likes and dislikes.* This was the same student who said and was quoted earlier: '*Models reflect what I usually think of, what I usually get in contact with, things I understand most; it's experiential*'.

While the lower years have yet to develop skills in integration and reflective thinking, the fact that their models are limited in expression, poses a challenge among teachers in the department to assist these students in either two ways or combination of these. First, teachers can vary their use of models in the classroom, with special consideration of the students' background and relevance of the model. Second, there must be more opportunities for student-generated models. This study showed that modeling activities were rare; and mostly these occurred in their biology-related subjects and chemistry. Of those classes, the frequency of modeling activities was limited. According to the students, modeling activities occurred between 3 to 5 times in a semester, and this number covered those classes that do engage them. The students were aware though, that while on the one hand modeling activity must be encouraged among teachers, on the other hand careful planning including timing and relevance of the activity must also be considered. An allusion to this is evident in the following interview transcript from a first year student: *'Try to find some sort of application even for the sake of understanding it better. And I think modeling is a way to do it'*. She continues by saying: *'Well, not in all subjects though. There are times when one model is better to explain. What I can add though is for teachers to explore other ways of modeling like animation, models that may move…multimedia…yeah. It would help a lot.* Among the first year students, this one is more conversant and assertive at expressing her thoughts.

In general, the modeling behavior of biology students is consistent with earlier works done on modeling particularly that of Hodgson and Harpster (1997) cited in Harrison and Treagust (1998). The model for the modeling process revolves on the following activities: one builds the model, assesses its validity with regard to the underlying problem situation, and revises accordingly. However, this model does not show the intricacies attached to the creation of models, which this paper addresses.

What do the models and modeling behavior of biology majors imply?

The types of models biology majors use were mostly analogies coupled with drawings and textbook definitions as were evident in the model making activities by the students. In the interview however, most students claimed awareness of various types of models.

In making their respective models, students point to a combination of activities like reading text, outlining of similarities either in structure or function between the concept and the model then reviewing or revising the model for appropriateness or correctness (Figure 11). Such modeling behavior may be likened to an earlier work by Hitt and Townsend (2004), where they describe a modeling activity based on the 5E learning cycle (engage, explore, explain, elaborate and evaluate) as an attempt to guide students through levels of understanding chemistry. In this study, the part where students read text, recall past lessons, consider similarities of the concept and the model and reviewing and revising their model is similar to what Hitt and Townsend (2004) refer to in their paper as engage, explore and evaluate respectively.

From the foregoing activities on model making, survey questionnaire and selected interviews, the students demonstrated critical thinking skills; like recognizing similarities in structure and function between the concept and their model, evaluating their own model, clarifying misconceptions, summarizing important details, relating concept to reality and explaining and defending their model. These were evident in the following claims by the students during the interview. *"With model making, I learned to evaluate myself and get to see what I know". "Model making helps you think critically especially when asked to explain or defend your model". "Model making facilitates creative thinking as you are being careful of what to represent". "Model making gives a chance to think critically as I review the correctness of my model". "Model making empowers you as it enhances your ability to think creatively and effectively".*

Of the students who were interviewed, very few showed abilities of integration and reflective thinking in their models. There were also students who simply copied textbook definitions of their models.

Conclusion

Data from the modeling activity and interview transcripts showed that biology students chiefly prefer analogies and drawings as models. Although the familiarity they have with a wide range of models is impressive. This is helpful information for teachers, particularly in considering other models as equally useful in developing critical thinking among students. Also, it was noted that among the students who were interviewed, the fourth year students were more elaborate and certain in describing the process of making their models.

Overall, the students demonstrated thinking skills, although there were some, the first and second year students in particular, who need improving and assistance with developing integration and reflective thinking.

Because the student-generated models were limited to analogies and drawings, teachers must try to use other models, if possible encourage students to explore multiple models whenever they engage in modeling activities.

Future studies along this line should include the conduct of classroom observations with regard to modeling activities and the student-generated models that result from the same; as this was not explored in this paper.

Finally, a study on how teachers view models and modeling, including their modeling behavior would be worthwhile, if teachers were to truly assist students in developing skills like integration and reflective thinking.

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