TYPES OF MODELS AND MODELING BEHAVIOR OF BIOLOGY MAJORS: IMPLICATIONS FOR CRITICAL THINKING DEVELOPMENT

Partosa, Jocelyn D
Ateneo de Zamboanga University, Zamboanga City, Philippines
ojdpartosa@yahoo.com

Abstract: Identifying and investigating student-generated models and their modeling behavior have implications for critical thinking development. Thus, this paper describes the types of models that biology majors use including their modeling behavior 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 who were 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. This was followed by having them complete an open-ended questionnaire. In the second phase of the study, only five students from each year level were randomly selected for a one-on-one interview. Data from the modeling activity and open-ended survey questionnaire were analyzed using Harrison and Treagust's typology of concept-building analogical models as basis for identifying the type of model biology students used. Results showed that the student-generated models from all year levels were mostly analogies, some textbook definitions and occasional drawings. However the familiarity that students have with a wide range of models was notable. The modeling behavior of students mainly consists of first, text reading or memory recall; second, outlining of similarities in function, structure and composition or both; and third, making the model, which for many of the student-generated models were in the forms of analogies and some drawings. Data suggest that models are good diagnostic tools. The critical thinking skills of students revolve on recognizing similarities in structure and function between the concept and their model. More opportunities for student-generated models must be available if students were to develop integration and reflective thinking in their models, as some senior students were found to demonstrate.

Keywords: Models, modeling, critical thinking

Introduction

The use of models and modeling in science teaching is the teacher's attempt to facilitate understanding of concepts. According to Erduran and Duschl (2004) models and modeling are a significant topic in cognitive psychology, philosophy of science, chemistry and chemistry education. Erduran and Duschl (2004) describe models as central to analogical reasoning, model-based reasoning, problem-solving and that models are keys to summarizing data, making predictions, justifying outcomes and facilitating communication in science.

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).

One of the more frequently used models is analogy. In science and science education, analogies are used to explain ideas and models to other people (Cosgrove, 1995; Holyoak and Thagard, 1997; cited in Coll and Treagust, 2002). According to Harrison (2002), analogies are interesting and motivating for learners when the teacher's analog can be enriched from the students' own experience. Analogies also reveal prior conceptions of learners and provide insights as to how the learners find ways in making it easier to explain observed phenomena (Coll and Treagust, 2002).

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).

Despite the extensive use of analogies, concept maps and diagrams in the classroom, few studies give attention to the type of models and modeling learners use and how they use the same in facilitating their learning. In this light, identifying and investigating student-generated models and modeling have implications for critical thinking development.

Thus, this paper explores the types of models biology majors use including their modeling behavior 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. To consider how students model such understanding as was evident in their models and modeling provides biology teachers with data as to which model advances critical thinking development in students.

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. Draw implications from the models of students vis-à-vis critical thinking development. Models as defined by Gilbert and Boulter (1998) are representations of an idea, an object, an event, a process or a system. Modeling as defined by Hodgson and Harpster (1997) is a cyclic problem-solving process, which in this study refers to how best the respondents represented the concepts in their respective models. In this cyclic problem-solving process, as Hodgson and Harpster suggest, one builds the model, assesses its validity with regard to the underlying problem situation, and revises accordingly.

Thus the working framework of this study says that the types of student-generated models can provide an index into the students' conceptual understanding and may have implications as to which type/s of model/s advance/s critical thinking development. Whether a type of model fosters critical thinking development, may be evident in the students' conceptual understanding of key concepts in biology (Figure 1).

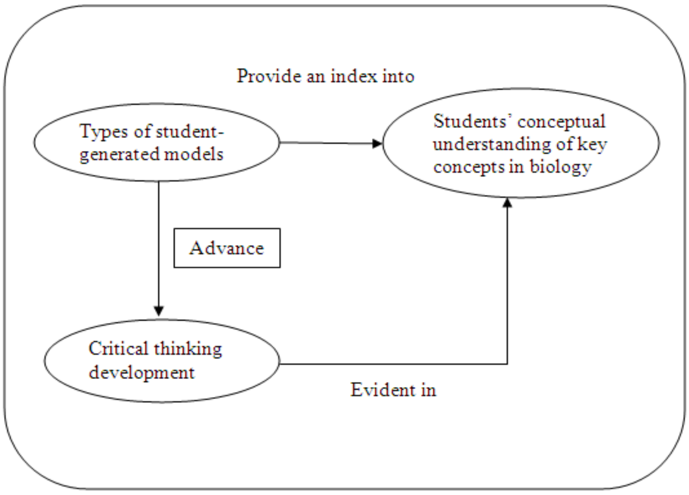


Fig 1 Student-generated models and Critical Thinking Development

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. Thus, developing in them metacognitive awareness; which according to Carey (1985) and Limon (2002) cited in (Rebich and Gautier, 2005), is awareness of one's own learning and is crucial although, an insufficient condition for conceptual change. Second, recognizing biology majors' models including their modeling behavior will help teachers determine which model advances critical thinking. 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 including the modeling behavior of biology majors. At the outset, all biology students were surveyed using an open-ended questionnaire. Also, students were asked to make models of the cell membrane, cytoskeleton and cell structure, to help identify the type of model students' use. One-on-one interviews with selected biology students formed the final phase of this study.

2. Sampling Design

Initially, a total of 44 students from all year levels were surveyed using an open-ended questionnaire. There were 13 first year, 5 second year, 9 third year and 17 fourth year students.

Five regular (those who are on track with the subjects in the curriculum) biology students from each year level were randomly selected for the interview phase of the study.

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 (Figure 2).

To help the author identify the model biology students use, students were asked to make models of the cell membrane, cytoskeleton and cell structure.

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 those 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? [You can name as many as you can]
6. How often do you use those 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?

Fig 2 Open-ended survey questionnaire

3. Data Gathering Procedure

First, on separate occasions, all year levels of biology students were asked to make models of the cell membrane, cytoskeleton and cell structure. Second, they were asked to complete the 9-item open-ended survey questionnaire.

Five biology students from each year level were randomly selected for the interview phase of the study. However, students who were absent during the conduct of the survey and modeling activity were excluded from the selection process for the interview.

Results of the modeling activity by the students formed the basis for probing students on their use of a particular model or a combination of models and whether they found those models helpful in learning science concepts.

4. Data Analysis

The type of model a student used was identified using a typology of concept-building analogical models adopted from Harrison and Treagust (1998). The modeling behavior of students was described following their personal accounts of their modeling behavior.

Results and Discussion

Research on student-generated models and modeling activity is pivotal in fostering critical thinking development. Table 1 summarizes the types of models biology majors used as evidenced by their modeling activity, including the other models they are familiar with and those they think fit their definition of models.

Table 1 Types of Models 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),	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),	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),

The student-generated models from all year levels (Table 1) mainly consist of analogies, some textbook definitions and occasional drawings. However, the familiarity students have with a wide range of models is notable. The ease in using analogies and its appropriateness when it comes to students, possibly explains the disparity here. To quote, 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'*. This student used the skin, spring bed and macaroni salad to represent the cell membrane, cytoskeleton and cell structure respectively (Figure 3). When asked as to the basis of her analogies, she recounted *"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'*. Aside from function, the student also considered the property and composition of her models to represent the concepts.

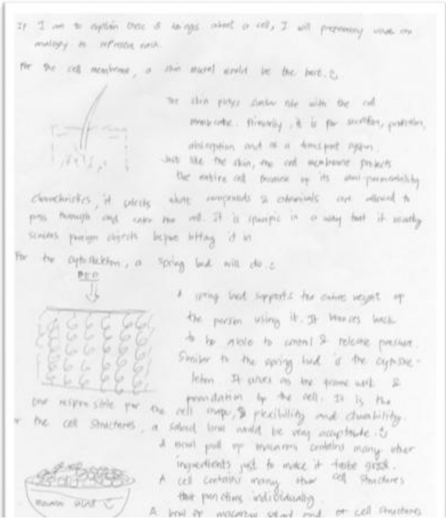


Fig 3 Sample model from a fourth year biology student

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.

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 are common (Table 1).

Despite the infrequent use of drawings by students in this study, it is important to mention that those students, who did, used one drawing to represent all three concepts. For example, one student, when asked why she came up with one drawing for all three concepts, narrated *'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).

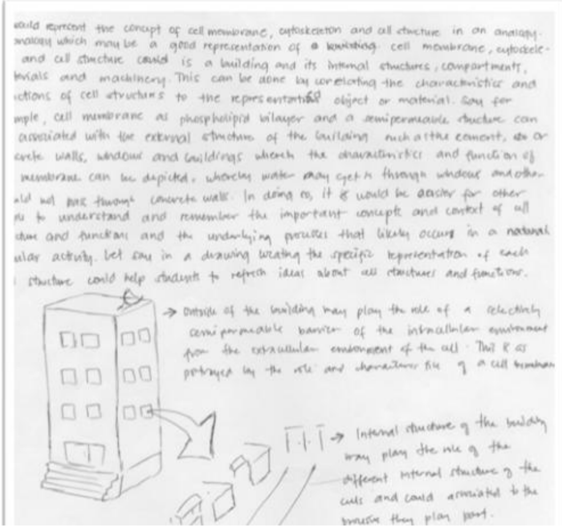
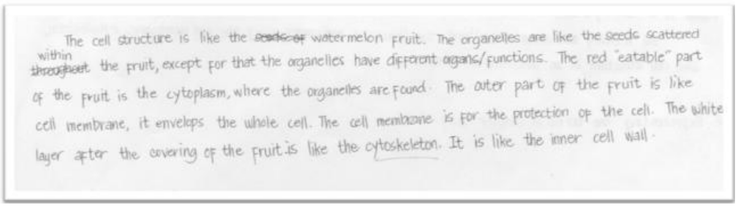


Fig 4 Sample from a fourth year biology student

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 3 concepts in one object. Her ability to see the relationship of the 3 possibly stems from an extensive background she amassed through the years from her majors like cell and molecular biology and vertebrate embryology.

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 offered. Some of their common replies were: *'I am not sure'* and *'I don't know'*. Figures 5, 6 and 7 are sample models from first, second and third year students respectively.


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.

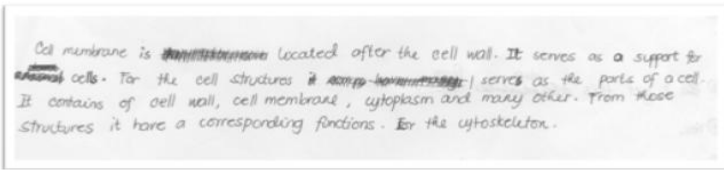

Cell membrane is ~~[illegible]~~ located after the cell wall. It serves as a support for ~~[illegible]~~ cells. For the cell structures ~~[illegible]~~ serves as the parts of a cell. It contains of cell wall, cell membrane, cytoplasm and many other. From those structures it have a corresponding functions.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

Fig 5 Sample models from first year biology students

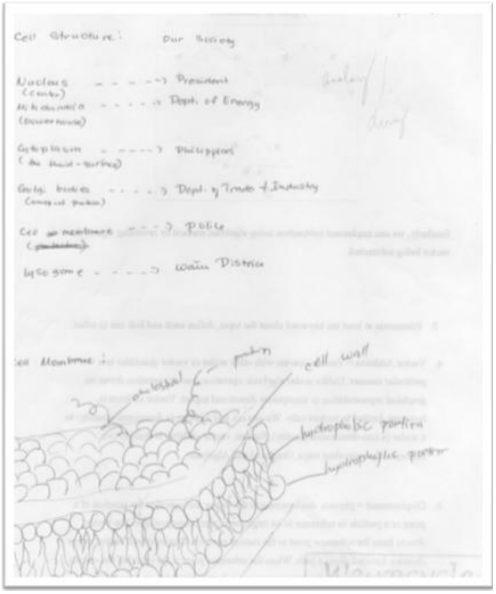


Fig 6 Sample model from a second year biology student

Fig 7 Sample model from a third year biology student

All the 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.

Figure 8 describes the modeling behavior of biology students when asked regarding how they made their respective models.

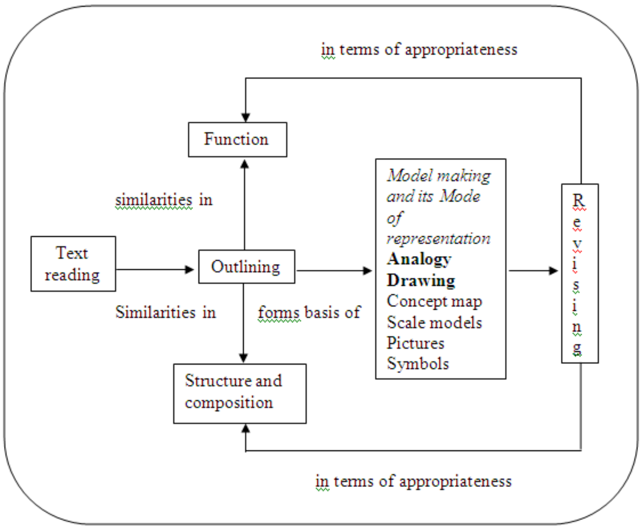


Fig 8 Biology majors' modeling behavior

The modeling behavior of biology students (who were interviewed) consists of text reading or memory recall, outlining of similarities in 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 two fourth year students, Dana and Tino (not their real names), who were each asked to describe how they made their respective models.

Dana: *'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.*

Tino: *'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.*

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 are rare; and mostly these come from their biology-related subjects and chemistry. Of those classes, the frequency of modeling activities is limited. According to students, modeling activities occur between 3 to 5 times in a semester, and this number covers 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 lines 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 including their modeling behavior suggest the following: First, the critical thinking skills of students chiefly revolve on recognizing similarities in structure and function between the concept and their model. Second, more opportunities for student-generated models must be available if students were to develop integration and reflective thinking in their models; as some senior students were found to demonstrate. This suggests that some of the students are already capable of integration and reflective thinking. Third, some students were observed to simply copy textbook definitions of their models. Self-monitoring processes must be encouraged among students if they were to become critical thinkers particularly those in the lower years. Finally, though not fully explored here, models are good diagnostic tools, as they reveal misconceptions of students.

Conclusion

Data from the modeling activity and interview transcripts revealed 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 endeavor to use other models, if possible encourage students to explore multiple models whenever they engage in modeling activities.

Future studies along this line could endeavor to conduct 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.

Acknowledgments

I thank the BS Biology students for their generous time.

References

Chang, S. (2007). Externalizing students' mental models through concept maps. *Journal of Biology Education*. 41 (3) p 107-112

Coll, R. and D F Treagust. (2002). Learners' use of analogy and alternative conceptions for chemical bonding: A Cross-age study. *Australian Science Teacher Journal.* 48 (1). p 24-32.

Erduran, S and R A Duschl. (2004). Interdisciplinary characterization of models and the nature of chemical knowledge in the classroom. *Studies in Science* Education. 40 p 105-138.

Flávia, P, M Ferreira and R Justi. (2007). Teachers' role in planning and conducting modeling activities in science teaching. *Journal of Science* Education. 8 (2) p 66-69.

Gilbert, J. and C. J. Boulter. (1998). Learning science through models and modeling. In B. Frazer and K. Tobin (Eds). The International Handbook of Science Education. P 53-66

Hodgson, T. and D. Harpster. (1997). Looking back in mathematical modeling: Classroom observations and Instructional strategies. *School Science and Mathematics*. 97 (5) p 260-267

Harrison, A G and D F Treagust. (1998). Modeling in science lessons: Are there better ways to learn with models? *School Science and* Mathematics. 98 (8). p 420-429.

Rebich, S and C Gautier. (2005). Concept mapping to reveal prior knowledge and conceptual change in a mock summit course on global climate change. *Journal of Geoscience* Education. 53 (4). p 39-43.

Yost, R. and E. L. F. Gonzalez. (2008). A coral reef as an analogical model to promote collaborative learning on cultural and ethnic diversity in science. *The American Biology Teacher*. 70 (1). P 39-43