Promoting Biological Knowledge Generation using Model-Based Inquiry Instruction

Vivien Mweene Chabalengula & Frackson Mumba

Department of Curriculum and Instruction, Southern Illinois University

Carbondale, IL 62901, USA

mweene@siu.edu

Abstract

This study examined the impact of a Model-Based Inquiry Instruction (MBII) using a human leg model, on 20 pre-service elementary teachers' knowledge generation and understanding of how a human leg functions when one is lifting or putting down the foot. Data was collected using the pre-and post-model drawings of a human leg which required students to show and label the eight parts (upper leg, lower leg, knee joint, foot, ankle joint, muscles, tendons and ligaments. Note: these parts were the foci because the model represented these parts); knowledge tests based on these parts, and perception questionnaire which required students to indicate how the model helped them to generate knowledge. Five major findings were revealed: First, majority of the students provided acceptable drawings of the human leg both before and after the MBII. Second, with respect to the positioning of leg structures/parts, none of the students could position all eight parts in the correct place during the pre-model drawing session. However, after the MBII, 50% of students located all eight structures in the correct place. Third, none of the students in the pre-model drawings could label all 8 structures correctly, but after MBII, 30% of students correctly labeled all 8 structures. Fourth, many students gained better conceptual understanding of how a human leg functions and achieved higher test scores (pre-model test average score was 60.3% whereas post-model test average score was 83.6%). Fifth, with respect to students' perceptions about the human leg model, nearly all students thought that the human leg model helped them understand the location of parts in the leg, and enabled them to see how these parts function when the model is manipulated. Implications for MBII in pre-service science teacher education are discussed.

Key words: biological knowledge, human leg, inquiry, knowledge generation, model

Introduction

Currently, inquiry science teaching has been an important focus in American science classrooms (NRC, 2000). However, several science education researchers have stated that inquiry as commonly practiced in science classrooms, is content-less and offers little possibilities for students to make connections between empirical data and unobservable processes, as wells as to provide content-bound explanations that connect empirical data with underlying causes for why something happens (Banilower, Smith, Weiss & Pasley, 2006; Windschitl, Thompson & Braaten, 2008). Furthermore, other researchers (e.g. Carey, Evans, Honda, Jay & Unger, 1989; Chinn & Malhotra, 2002) found that students are rarely given the sense-making contexts, particularly models, within which to understand why things happen as they do in our natural world.

Reversing this current trend of inquiry activities calls for a re-imagining of implementable frameworks for inquiry in science classrooms at all levels that engage learners deeply with content and with the epistemic practices of authentic science. As such, we propose that inquiry activities be based on the generation or construction of knowledge by students themselves using a Model-Based Inquiry Instruction (MBII). In this paper, we will define a scientific model as a representation that simplifies a system or process of a biological phenomenon by focusing on key features to illustrate, explain, predict, and to communicate scientific phenomena (Harrison & Treagust, 2000). Schwarz et al (2007) state that inquiry practices play a central role in generating scientific knowledge, whereas models are essential tools for productive scientific reasoning among leaners. Science instructional practices focused on scientific inquiry and modeling can help learners develop deep understanding of subject matter and develop science process skills (Lehrer & Schauble, 2000; NRC, 2000; Schwarz & White, 2005), which are essential for the promotion of scientific literacy among all citizens. With respect to biology education, some researchers have investigated the impacts of model-based inquiry on students' conceptual understanding of biological processes and phenomena (e.g. Haugwitz & Sandmann, 2010; Lee, 2004; Rotbain, Marbach-Ad & Stavy, 2006). Haugwitz et al (2010) conducted a study aimed at determining how the models of the heart, pulse and veins would enhance students' understanding of function of heart and blood vessels among 40 seventh grade German students. These students were asked to verify hypothesis, plan, construct models, manipulate models illustrating how heart and blood vessels work, discuss results, think about the models and determine what model materials represented in their own bodies, and finally took a pre- and post-test which measured their interest in learning with models & their content knowledge achievement. The results showed three findings: most students found learning with models very interesting; students gained better biological knowledge understanding of function of human heart & vascular system; and students achieved higher test scores after using the models (pre-test average score was 51% whereas post-test score was 64%). In another study, Rotbain et al (2006) explored if the use of bead illustration model in molecular genetics can contribute to students' understanding of genetics concepts and processes among 258 Israeli high school biology students. Before instruction, all students were given a multiple-choice pre-test which covered the structure of DNA and RNA, molecular processes such as DNA replication, transcription, translation; & conceptual relationships between genetic material and its products. The control group (116 students) was taught in traditional lecture forma, whereas the experimental group (142 students) was taught with a bead illustration model. At the end of instruction, achievement data was collected using multiple-choice, open-ended written questionnaire and personal interviews. The results showed the following: Students who used the bead model improved their knowledge in molecular genetics compared to the control group; open-ended questions revealed that the bead model was significantly more effective than traditional lecture; and the bead model improved student achievement scores in comparison to traditional instruction. Lee (2004) used the pig heart model to demonstrate blood flow from coronary arteries to veins, as well as the blockage of the coronary arteries in coronary artery diseases, in one class of senior secondary students in Hong Kong. The results showed that the model reinforced students' understanding of the circulatory system (particularly the role of arteries, veins and function of coronary circulation); and that the model successfully enhanced many students' understanding of causes and effects of coronary heart disease.

Despite the positive impacts of using model-based inquiry as shown in the studies cited above, Schwarz and Gwekwerere (2007) state that whilst inquiry has been an important focus in science classrooms, modeling has not been routinely practiced in schools. The reasons proposed for this trend by some authors included: the persistence of education theories that focus on simple reasoning skills for young learners and complex forms of reasoning for older and more capable students (Schauble, Glaser, Duschl, Schulze & John, 1995); and the lack of existing information, frameworks, and structures for guiding teachers in engaging learners in model-based inquiry practices (Schwarz et al, 2007). Furthermore, Windschitl et al (2008) argue that a few science teachers who employ models tend to use them as end-products of inquiry rather than as tools to help students explain and generate knowledge about concepts being illustrated at any point in the inquiry. In addition, other researchers (e.g. Justi & Gilbert, 2002; Van Driel & Verloop, 2002) state that most teachers do not realize the value of using models in science teaching, and do not know how to effectively engage their students in modeling. The arguments put forth by these authors about inquiry and modeling have been the rationale for our study. In an ideal situation, we believe that there is need for science teacher educators to involve pre-service and in-service teachers to construct and use models in their inquiry practices so that they can see the potential of models in terms of helping them generate knowledge for themselves as they manipulate the models.

Therefore, the purpose of our study was twofold: (1) to involve pre-service teachers in constructing and using a human leg model so that they can generate their own knowledge about how a human leg functions when one is lifting or putting down the foot; and (2) to determine pre-service teachers' perceptions about the human leg model after they constructed and used it as a knowledge generating tool. We believe that successful inquiry-instructional frameworks for modeling in science education (particularly in biology) should typically guide students through a number of epistemic processes such as: engaging with a question or problem (often through material involvement with a natural phenomenon); developing/constructing a model about causal or otherwise associative relationships in the phenomenon; manipulating or using the model in order to make systematic observations and generate knowledge; and using the systematic observations to come up with scientific explanations for the science phenomenon being illustrated in the model.

Method

Participants

Our Model-Based Inquiry Instruction using a human leg model was implemented among 20 pre-service elementary teachers enrolled in an Advanced Science Methods Course, at a university in the Midwest of the USA. There were 16 females and 4 males. Twelve of these participants had taken biology courses previously, as well as a mandatory integrated science course which covers science concepts in biology, chemistry, physics and earth science. None of the participants had a school teaching experience.

The human leg model used in this study was implemented with all the 20 participants. Whilst a comparison group (which did not experience the model) would have been of value in making conclusions about the impact of the model, our study defined the positive impact of the model on two bases which are the pre-and post-test knowledge scores, and the students' perception survey about the model.

Model-Based Inquiry Instruction Progression framework

Scientific modeling is a rich practice, and contains many elements in which designers might choose to involve learners. Based on previous work on student learning about modeling (e.g. Grosslight et al, 1991; Snir et al, 2003; Spitulnik et al, 1999; Stewart, Cartier & Passmore, 2005), design-based practices such as design, test, and revise (Fortus et al, 2005), and mathematical modeling practices such as describe, manipulate, translate, and verify (Lesh & Doerr, 2003), several authors have operationalized instructional frameworks for student modeling activities. For example, Schwarz and Gwekwerere (2007) operationalized a guided inquiry and modeling instructional framework, EIMA (Engage-Investigate-Model-Apply). Under EIMA, students are engaged in the topic to elicit their prior ideas; students investigate the topic/phenomena with high priority for data collection and analysis of those data into patterns; students create models (that account for causal aspects of the phenomena or represent patterns in the phenomena) or explanations (that include a particular claim and reason for the phenomena); and students apply those models or explanations to novel situations.

In our study, we adopted Schwarz et al (2007)'s inquiry and modeling framework, but made some modifications in order to fit them in the 5E Inquiry Learning Cycle (i.e. Engage, Explore, Explain, Elaborate and Evaluate), developed by the Biological Sciences Curriculum Study (Bybee, 1997). Specific changes we made include: referring the Investigate phase to Explore phase; referring to Model phase to Explain phase; and adding another phase called Evaluate phase. From our teaching experience in our science methods courses, we have observed that the 5E inquiry cycle has helped our pre-service teachers to ensure that their lesson plans include aspects where their students would explore with the model, explain their observations from the explore stage, and also allows pre-service teachers to have an effective evaluation plan for their lessons. The Engagement phase helps to unpack the learning goals and draws out the implicit understandings they entail (Krajcik et al, 2008), thereby helping students to understand the purpose of the model or model features and why those model features are important (Schwarz, 2002; Schwarz, et al, 2005). The Exploration phase allows students to construct and manipulate models to articulate their own understanding of how a scientific phenomenon behaves (Acher et al, 2007; Schwarz et al, 2005; Wilensky & Reisman, 2006; Windschitl et al., 2008). One point to note here is that of Schwarz et al (2009), who argue that constructing models is least emphasized in schools – and this has been one of the impetus for our study. The Explanation phase enables students to use and manipulate models in order to generate explanations about how phenomenon works (Schwarz et al, 2009). This stage also helps participants to realize that models are not just end-products of inquiry, but as explanatory tools aiding in knowledge generation. The evaluation phase allows students to reflect on both the effectiveness and accuracy of the model, as well as on their understanding in more effective ways and improve on explanations of phenomena (Schwarz et al, 2007).

Model used in this study

In our study we used a human leg model adopted from the FOSS (Full Option Science System) Kits developed at the University of California, Berkeley, USA. This model was used a knowledge generation tool aimed at demonstrating how a human leg and its associated structures function when one is lifting and putting down the foot. FOSS develops research-based and inquiry-based science curriculum materials for grades K—8. This human leg model is constructed using the following materials: two 18cm dowels (representing upper and lower leg bones); 1 rubber tube with no hole (representing ligament); 1 rubber tube with a hole (representing a joint); one 11cm popsicle stick with two hole (representing foot); 3 large rubber bands (representing muscles); and 6 regular sized paper clips (representing tendons). The human leg model construction video is found at this website: http://lhsfoss.org/fossweb/schools/teachervideos/3_4/HumanBody_flash.html. Figure 1 shows the constructed human leg model.

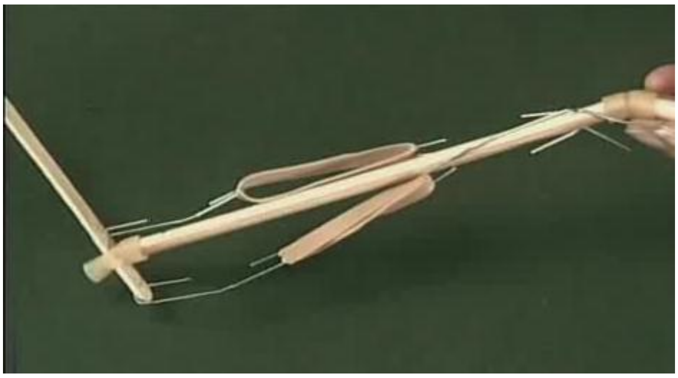


Figure 1: Human Leg Model

Implementation of the MBII within the 5E Learning Cycle

After students did the pre-model drawings and took the pre-model knowledge test, they were involved in a MBII Unit on how a human leg functions when one is walking using the 5E Learning Cycle. Before the actual lesson, the instructor of the course (who happens to be the lead author of this paper) made some preparation with respect to the following: stating the goal that pre-service teachers were supposed to learn from this activity, phrasing the lesson/activity objectives in question form so that participants can check if the model helped them achieve the goals, gathering the materials, and assessing whether some students had visual impairments so that they could be accommodated (since actual observations of the model being manipulated were key to knowledge generation).

Goals of the model activity: This activity enabled pre-service teachers to make a model of human leg to show the leg bones, ankle, muscles, joints, tendons and ligaments work together when a person is walking. It also provided pre-service teachers, with hands-on experiences on how they can use the modeling teaching approach using the 5E Learning Cycle Model (Engage, Explore, Explain, Elaborate and Evaluate) to explain some science concepts.

Model activity objectives: As they conducted this activity, participants were to determine if the model helped them to generate their own knowledge about the following concepts (in Table 1) on how the human leg functions before the instructors formally taught the concepts.

Table 1. *Human model lesson objectives*

Science concepts on Human Leg to be taught to students	**Activity helped you generate knowledge about these concepts**	
	Yes	No
1. 1. What do the following model parts represent in your own body?		
2. a). Two Long dowels –		
3. b). Short popsicle stick-		
4. c). Rubber tube with NO hole-		
5. d). Rubber tube with hole-		
6. e). Paper clips-		
7. f). Rubber bands-		
8. 2. What parts of the leg are involved when one is walking?		
9. 3. What happens to the leg muscles when you lift your foot?		
10. 4. What happens to the leg muscles when you put down your foot?		

Model construction materials: 2 dowels (18cm); 1 rubber tube (no hole); 1 rubber tube (with hole); 1 popsicle stick (with holes & 11 cm); 3 large rubber bands; and 6 paper clips (regular size).

Student accommodation: Since no students required special assistance due to visual problems, students were randomly assigned to a group.

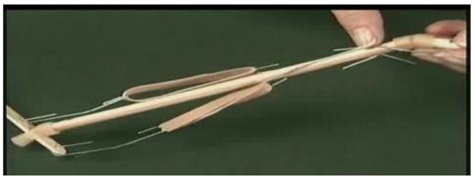
After the preparation stages, the instructor then started the lesson, and here is how it was typically enacted.

Engagement Phase: Before the lesson started, we engaged students by asking them to draw the human leg, and label these eight parts: upper leg, lower leg, knee joint, foot, ankle joint, muscles, tendons and ligaments. We also asked them to respond to 5 open ended questions based on these eight parts. This was done in order to elicit their prior ideas about the phenomena we are going to cover. When students completed their drawings and pre-instruction test, we collected the answer sheets. Thereafter, we introduced the lesson by asking this question: "How are you able to lift your leg bones and foot when walking?" students provided us with various answers, which we recorded. Without telling the students the answers to the above question, we instead involved them in constructing a human leg model to show how the leg bones and its associated structures aid a person to lift the leg and the foot when walking. To aid students in the construction, we provided materials and directions in both print and pictorial as shown below:

1. Using two long dowels, popsicle stick, rubber tube without a hole and rubber tube with a hole, construct a jointed leg and foot. Use the pictures below.


2. Then using 1 rubber band and 2 standard paper clips, add a muscle to the model leg that will bend the knee. Open the paper clips to make as "S" hook. Use the pictures below.

3. Now, using 2 rubber bands and 4 paper clips, attach two more muscles to the leg model, one that makes the toe point down, AND one that lifts the toe up. Use the pictures below.



Exploration Phase: After the construction of the human leg in the engagement phase, we involved students in the actual manipulation of the model. We told them to do the following task: Using your model, manipulate it and demonstrate the three functions the leg can perform (foot/toe up, foot/toe down & knee bend). Use the pictures below.

Foot/toe up

Foot/toe down

As students manipulated the model, we asked them to answer the following questions:

1. What do you think might happen to the leg muscles if pull the foot up? Perform the function and observe?
2. What do you think might happen to the leg muscles if put the foot down? Perform the function and observe?

Explanation Phase: As students were manipulating the model, they had to generate their own knowledge to answer the lesson objectives indicated in Table 2.

Elaboration and Evaluation Phase: In order for students to apply their knowledge to the actual human leg, they were asked to:

1. Name the actual body parts represented in the model.
2. Explain how the actual leg system works during walking, using the model.

Data collection instruments and analysis

Data were collected using three instruments: pre- and post-model students' drawings of a human leg; pre- and post-model knowledge test; and post-model perception questionnaire.

Pre- and post-model students' drawings: The drawing sessions required students to draw the human leg, locating and labeling the eight parts which are: upper leg, lower leg, knee joint, foot, ankle joint, muscles, tendons and ligaments. We asked students to consider these 8 structures because they are the ones represented in the human leg model which we adopted from the FOSS (Full Option Science System) Kits website at: http://lhsfoss.org/fossweb/schools/teachervideos/3_4/HumanBody_flash.html. Student drawings and labels were analyzed and categorized as either acceptable or unacceptable, and correct or incorrect, respectively. A human leg drawing was considered acceptable if it showed the upper leg, lower leg, knee joint between upper and lower leg, foot, and ankle joint between the lower leg and foot. We considered these key features because they help one to at least identify the drawing as a leg. If the drawing did not have these key features, it was considered unacceptable. With respect to labeling the human leg, we required students to position and label eight parts stated above.

Pre- and post-model knowledge test: The pre- and post-model knowledge test consisted of the same 5 open-ended questions based on the eight structures illustrated in the human leg model (Table 4 shows these questions). These questions required students to respond using one word or short phrase. These tests were graded and scored as either correct or incorrect. Thereafter percentages of students who got each item correct or incorrect were calculated. The reliability of the pre-model test was 0.76, whereas that of the post-model test was 0.90. To further determine the impact of the human leg model on students' knowledge generation and understanding, a paired samples t-test was computed to compare the pre- and post-model knowledge test scores.

Post-model perception questionnaire: The post-model perception questionnaire consisted of four open-ended questions which asked students about whether the model helped them generate knowledge, and provide any strengths and weaknesses of the model (Table 5 shows these questions). Students' perceptions were coded, categorized according to themes, and then presented in terms of percentages.

Results

The results are organized in three sections: students' drawings and labels of human leg; students' knowledge about human leg parts involved when walking; and students' perceptions of the human leg model they constructed and used to generate knowledge.

Students' drawings and labels of human leg

Table 2 shows that majority of the students provided acceptable drawings of the human leg for the pre-model (85%) and post-model (90%). With respect to the positioning of leg structures/parts, none could position all eight parts in the correct place during the pre-model drawing session, but after the MBII, 50% of students located all eight structures in the correct place. With regard to labeling the structures, none of the students in the pre-model drawings could label all 8 structures correctly, but after MBII, 30% of students correctly labeled all 8 structures.

Table 2. *Students' human leg drawings and labels*

Students' Drawings of human leg	Pre-model drawings (%)	Post-model drawings (%)
Drawings		
Drawings Acceptable	85	90
Drawings Unacceptable	10	10
No Drawings provided	I	0
Positioning of Structures		
All 8 structures positioned in correct place	0	50
5-7 structures positioned in correct place	50	75
1-4 structures positioned in correct place	20	0
Labelling of Structures		
All 8 structures labelled correctly	0	30
5-7 structures labelled correctly	25	40
1-4 structures labelled correctly	65	30

Students' knowledge about human leg parts involved when walking

The pre- and post-model knowledge test revealed five interesting trends, as shown in Table 3. First, students gained better biological understanding of how a human leg functions when one is lifting or putting down the foot. This was demonstrated in the test scores in which students achieved higher test scores after using the model (pre-model test average score was 60.3% whereas post-model test average score was 83.6%).

Second, most the students had better knowledge to test items 1 (i.e. knee/knee joint is a place where upper and lower leg meet), 3 (muscle), 4 (muscles contract/relax), 5 (tendon functions to attach muscle to bone) and 8 (tendon is stronger than a ligament).

Third, majority of the students (75%) got test item #2 incorrect (i.e. they did not know that ligaments hold together two or more bones), with 10 % of other students leaving the question unanswered in the pre-model test. However, after the manipulation of the model, nearly all students (90%) got test item #2 correct.

Fourth, in the pre-model test, students provided contradictory answers to test items #5 and #6, both of which were testing if students knew that tendons attach muscle to bone, though phrased differently. That is, 70% of the students got test item #5 correct (tendon attaches muscle to bone), whereas only 30% got item #6 correct. Another point to note here is that 10% and 15% of the students left items #5 and #6 unanswered in the pre-model test, respectively. To the contrary, after using and manipulating the human leg model, 85% of the students got items #5 and #6 correct in the post-model test.

Fifth, most of the students (75%) got item #7 incorrect (i.e. most students did not know that a ligament attaches bone to bone), with 20% of them leaving the question unanswered in the pre-model test. However, after using the human leg model, 85% of the students got this item correct.

Table 3. *Students' responses to the knowledge test items about human leg*

Knowledge test items	**Pre-model Knowledge Test**			**Post-model Knowledge Test**	
	Correct (%)	Incorrect (%)	No Answer (%)	Correct (%)	Incorrect (%)
1. A----is a place where your upper leg and lower leg meet.	100	0	0	100	0
2. What structure holds together the upper leg bone and lower leg bone in your body?	15	75	10	90	10
3. What structure has the ability to contract and allows you to lift the leg bone when walking?	80	15	5	95	5
4. For the structure you named in question 3 above, what happens to it when you are walking?	95	0	5	100	0
5. For the structure you named in Question 3 above, what attaches it to your leg bone?	70	20	10	85	15
6.A ----attaches muscle to bone.	30	55	15	85	15
7.A-----attaches bone to bone.	5	75	20	85	15
8. Which one is stronger, a tendon or a ligament?	90	10	0	90	10

To further determine the impact of the human leg model on students' knowledge generation and understanding before and after a MBII, a paired samples t-test was computed, as shown in Table 4.

Table 4. *Comparing pre-model and post-model knowledge test*

Construct	Participants (N= 20)	Mean (SD)	t	df	*p*-value	Result
Pre-model test scores	20	4.85 (1.53)	-5.433	19	0.000	Significant
Post-model test scores	20	6.80 (1.39)				

Sig at p<.05

The t-test results showed that there was a significant difference in students' scores (t (19) = -5.433, p = 0.000), for pre-model test (Mean = 4.85) and post-model test (Mean = 6.80). These results suggest that use of a human leg model enabled students to generate their own knowledge and improved their understanding.

Students' perceptions after using the Human Leg model

Table 5 shows students' perceptions of the human leg model. Generally, the results showed four major aspects which are: majority of the students (60%) indicated that the model helped them to understand the location/positioning of body parts found in your upper and lower leg; nearly all students (80%) stated that the model enabled them to see how these leg parts (muscles, tendons, ligaments and bones) work/function when the model is manipulated; with respect to the strengths of the model, 55% and 40% of the students stated that the model can be manipulated to show muscle contraction and movement, and is a great visual representation of the human leg, respectively; and finally students noted two key weaknesses of the model which include non-representation of some parts such as a second bone in the lower leg (55%), and that the model was not completely accurate/not to scale with actual human parts (45%).

Table 5. *Students' perceptions about human leg model*

Post-Model Perception Questions	Categories of Students' Responses	Students (%)
In what ways did the model help you to understand the body parts found in your upper and lower leg?	- Shows location of bones, muscles, tendons, ligaments & joints.	60
	- Shows how bones, muscles, tendons, ligaments & joints move/function.	35
	- Shows how bones, muscles, tendons, ligaments & joints are connected/relate to each other.	15
In what ways did the model help you to understand how the leg parts function when you are walking?	- Able to see how muscles, tendons, ligaments & bones work/function together when the model is manipulated.	80
	- Able to see how muscles contract/expand.	20
What were the strengths of this human leg model?	- Can be manipulated (i.e. lift or put down the foot) to shows muscle contraction & movement	55
	- Great visual representation of human leg.	40
	- Provides better understanding of tendons, ligament & muscles.	10
What were the weaknesses of this human leg model?	- Some leg parts not represented (e.g. showed only one bone in lower leg, instead of two bones).	55
	- Not completely accurate/not to scale with actual human parts.	45
	- Knee joint movement was more than 180^o.	15

Discussion

Despite the current practice where many teachers tend to use models as end-products of inquiry (Windschitl et al, 2008), the results of our study indicate that the pre-service teachers benefitted a lot from using the human leg model as a knowledge-generating tool. With respect to biological understanding, students in our study, gained better biological understanding of how a human leg functions and they achieved higher test scores (pre-model test average score was 60.3% whereas post-model test average score was 83.6%). Our results are supported by previous authors who conducted similar studies using other biological models. For instance, Haugwitz et al (2010) found that the heart, pulse and vein models helped students gain better biological understanding of human heart and vascular system function, and that these students achieved higher test scores (pre-test average score was 51%

whereas post-test average score was 64%). In another study, Rotbain et al (2006) found that many students who used the bead model improved their knowledge and achievement scores in molecular genetics compared to the control group who used a traditional lecture.

With respect to students' perceptions about the human leg model, the following were evident: majority of the students thought that the human leg model helped them understand the location of parts in the leg; nearly all students were able to see how muscles, tendons, ligaments and bones work/function together when model was manipulated; more than half of the students stated that the strength of the model was that they manipulated it to show muscle contraction and movement; and that one of the weaknesses was the absence of some leg parts such as two bones in lower leg, but model only showed one bone. Similar results on students' positive perceptions about biological models were documented by previous researchers (e.g. Haugwitz et al, 2010; Rotbain et al, 2006). For example, Rotbain et al found that 86% of their participants stated that the bead model helped them to visualize the DNA, ribosome, mRNA, tRNA and the chain of the amino acids.

From the results of our study, it became apparent that our pre-service teachers were able to generate knowledge about how a human leg functions by actually manipulating the model to see what happens when one is lifting or putting down the foot. As such the model helps to reduce information represented in the textbooks, and thus helps students to understand the basic structure of the human leg as well as literally 'see' what happens to the model parts when it is manipulated.

The human leg model was done as a hands-on model-based inquiry activity, and came with a set of written and pictorial instructions that enabled students to construct the model independently in small groups, as well as guiding questions designed to focus students' attention on the main issues.

What this suggests is that the use of biological models should be included in the pre-service teacher education programs. Furthermore, models should be used as tools to help students generate knowledge rather than as end processes. If pre-service teachers are exposed to MBII, they would realize the value of using models in science, and consequently would effectively engage their students in scientific modeling. Another important aspect which emerged from our study is the idea of asking students to examine/evaluate the human leg model and determine the weaknesses when compared to the actual human leg. Previously, authors such as Schwarz et al (2009) have stated that evaluating models is the least aspect in which students are engaged in. From our perception survey component, pre-service teachers provided valuable weaknesses of the model, which instructors need to address upfront so that learners know the deficiencies. Involving students in examining the models would really help them to understand the role of models in science teaching – that is, they are used to show only specific features of the concepts being taught, and not accurately showing the exact replica of the actual body parts.

Implications for Science Teaching and Learning

Typically, classroom practice uses models for communication of (finalized) ideas, rather than as tools to help students generate their own knowledge (i.e. sense-making) about a science concept. Worse still, Schwarz and Gwekwerere (2007) state that construction of models as a sense-making tool is new to most teachers. Therefore, there is need to incorporate modeling and model construction training among pre-service teachers so that they can be competent and involve their future students in constructing and using models. This would ensure that young students are involved in generating knowledge by manipulating models other than just being told the answers by the teachers. As such, our findings are of great relevance to science educators (particularly biology) who are involved in pre-service teacher preparation and science education outreach programs. Science teacher educators should be aware of teaching strategies that qualify the inquiry science teaching such as models. This is because models create conditions for students to generate their own knowledge whilst manipulating the model, and could consequently lead to comprehensive scientific explanations for the observed scientific phenomena.

Implications

On the basis of our findings, we conclude that it is worthwhile to integrate physical model activities in the teaching of biological phenomena. From our experience, we recommend involving pre-service teachers to generate their own knowledge by manipulating the model(s) for two reasons: First, this would enable these would-be teachers to be competent and confident in using models. Second, it would to enable these future teachers to perceive models as knowledge generating tools, and not as end products to inquiry teaching. Our recommendation is also in harmony with the growing emphasis on integrating models in science education in general (e.g. Bailer-Jones, 2002; Giere, 1999; Gilbert & Boulter, 1998; Grandy, 2003; Magnani, et al, 2002; Van Driel & Verloop, 2002; Van der Valk, Van Driel, & De Vos, 2007). Recently, Acher et al (2007) also argued that putting this process of using models in science teaching into practice may enable pre-service teachers to see a different way of approaching what is seen as teaching and learning science, as well as how science knowledge is generated.

References

Acher, A., Arca, M. & Sanmarti, N. (2007). Modeling as a teaching learning process for understanding materials: A case study in primary education. *Science Education, 91*(3), 398–418.

Bailer-Jones, D. M. (2002). Scientists' thoughts on scientific models. *Perspectives on Science, 10*(3), 275–301.

Banilower, E., Smith, P. S., Weiss, I. R., & Pasley, J. D. (2006). The status of K-12 science teaching in the United States: Results from a national observation survey. In D. Sunal & E. Wright (Eds.), *The impact of the state and national standards on K-12 science teaching* (pp. 83 – 122). Greenwich, CT: Information Age Publishing.

Bybee, R. W. (1997). *Achieving scientific literacy: From purposes to practices*. Portsmouth, NH: Heinemann.

Carey, S., Evans, R., Honda, M., Jay, E. & Unger, C. (1989). "An experiment is when you try it and see if it works": A study of 7th grade students' understanding of the construction of scientific knowledge. *International Journal of Science Education, 11*, 514 – 529.

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

Fortus, D., Krajcik, J., Dershimer, R.C., Marx, R.W. & Mamlok-Naaman, R. (2005). Design-based science and real-world problem-solving. *International Journal of Science Education, 27*(7), 855–879.

FOSS (Full Option Science System). Retrieved on July 28, 2011, from http://lhsfoss.org/fossweb/schools/teachervideos/3_4/HumanBody_flash.html/.

Giere, R. N. (1999). Using models to represent reality. In L. Magnani, N. J. Nersessian, & P. Thagard (Eds.), *Model-based reasoning in scientific discovery* (pp. 41–57). New York: Kluwer Academic/Plenum Press.

Gilbert, J.K. & Boulter, C.J. (1998). Learning science through models and modelling. In B.J. Fraser & K.G. Tobin (Eds.), *International handbook of science education* (pp. 53–56). London: Kluwer Academic.

Grandy, R. (2003). What are models and why do we need them? *Science & Education, 12*, 773–777.

Grosslight, L., Unger, C., Jay, E. & Smith, C.L. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. *Journal of Research in Science Teaching, 28*, 799–822.

Harrison, A.G. & Treagust, D.F. (2000). A typology of school science models. *International Journal of Science Education*, *22*(9), 1011–1026.

Haugwitz, M. & Sandmann, A. (2010). Collaborative modelling of the vascular system – designing and evaluating a new learning method for secondary students. *Journal of Biological Education, 44*(3), 136-140.

Justi, R. & Gilbert, J. K. (2002). Science teachers' knowledge about and attitudes towards the use of models and modelling in learning science. *International Journal of Science Education*, *24*(12), 1273–1292.

Lee, Y. C. (2004) There is more to the dissection of a pig's heart. *Journal of Biological Education, 38* (4) 172-177.

Lehrer, R. & Schauble, L. (2000). Modeling in mathematics and science. In R. Glaser (Ed.), *Advances in instructional psychology: Volume 5: Educational design and cognitive science* (pp. 101 – 159). Mahwah, NJ: Erlbaum.

Lesh, R. & Doerr, H.M. (2003). Foundations of models and modeling perspective on mathematics teaching, learning, and problem solving. In R. Lesh & H.M. Doerr (Eds.), *Beyond constructivism: Models and modeling perspectives on mathematics problem solving, learning, and teaching* (pp. 3–33). Mahwah, NJ: Erlbaum.

Lesh, R., Hoover, M., Hole, B., Kelly, A. & Post, T. (2000b). Principles for developing thought revealing activities for students and teachers. In A. Kelly & R. Lesh (Eds.), *The handbook of research design in mathematics and science education* (pp. 591 – 646). Mahwah, NJ: Erlbaum.

Magnani, L., & Nersessian, N. J. (Eds.) (2002). *Model-based reasoning: Science, technology, values.* New York: Kluwer Academic/Plenum Press.

NRC (National Research Council). (2000). *Inquiry and the National Science Education Standards*. Washington, DC: National Academy Press.

Rotbain, Y., Marbach-Ad, G. & Stavy, R. (2006). Effect of bead and illustrations models on high school students' achievement in molecular genetics. *Journal of Research in Science Teaching, 43*(5), 500-529.

Schauble, L., Glaser, R., Duschl, R., Schulze, S. & John, J. (1995). Students' understanding of the objectives and procedures of experimentation in the science classroom. *Journal of the Learning Sciences, 4*(2), 131 – 166.

Schwarz, C.V. (2002). Is there a connection? The role of meta-modeling knowledge in learning with models. In P. Bell, R. Stevens, & T. Satwicz (Eds.). *Keeping learning complex: The Proceedings of the Fifth International Conference of the Learning Sciences* (ICLS). Mahwah, NJ: Erlbaum.

Schwarz, C.V. & Gwekwerere, Y.N. (2007). Using a guided inquiry and modeling instructional framework (EIMA) to support pre-service K-8 science teaching. *Science Education, 91*(1),

Schwarz, C. V. & White, B. Y. (2005). Metamodeling knowledge: Developing students' understanding of scientific modeling. *Cognition and Instruction, 23*(2), 165 – 205.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Acher, A., Fortus, D., Shwartz, Y., Hug, B. & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46*(6), 632–654.

Snir, J., Smith, C.L., & Raz, G. (2003). Linking phenomena with competing underlying models: A software tool for introducing students to the particulate nature of matter. *Science Education, 87*(6), 794–830.

Spitulnik, M.W., Krajcik, J., & Soloway, E. (1999). Construction of models to promote scientific understanding. In W. Feurzeig & N. Roberts (Eds.), *Modeling and simulation in science and mathematics education* (pp. 70–94). New York: Springer-Verlag.

Stewart, J., Hafner, R., Johnson, S., & Finkel E. (1992). Science as model-building: Computers and high school genetics. *Educational Psychologist, 27*(3), 317 – 336.

Stewart, J., Cartier, J.L. & Passmore, C.M. (2005). Developing understanding through model-based inquiry. In M.S. Donovan & J.D. Bransford (Eds.), *How students learn* (pp. 515–565). Washington, DC: National Research Council.

Van der Valk, T., Van Driel, J. H., & De Vos, W. (2007). Common characteristics of models in present-day scientific practice. *Research in Science Education, 37,* 469–488.

Van Driel, F.H. & Verloop, N. (2002). Experienced teachers' knowledge of teaching and learning of models and modeling in science education. *International Journal of Science Education, 24*, 1255–1272.

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

Windschitl, M., Thompson, J. & Braaten, M. (2008). Beyond the Scientific Method: Model-Based Inquiry as a New Paradigm of Preference for School Science Investigations. *Science Education*, *92*, 941 – 967.