An Exploratory Study Using Hands-On Physical Models in a Large Introductory, Earth Science Classroom: Student Attitudes and Lessons Learned

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Abstract

Students in nine sections of a large (n=160), introductory, undergraduate, earth science course manipulated physical models to enhance their conceptual learning. During each model activity, students worked within predetermined groups to make observations that emphasized key concepts and challenged inaccurate student conceptions of the target phenomenon. Data from student interviews and classroom observations indicated that the students believed that manipulating the models increased their attentiveness in class and provided a visual aid that they could later recall on the exam. Classroom observations indicated that students often used the models to explain the concepts to their peers, and also suggested that group dynamics may have contributed to the success of this pedagogy.

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Introduction

Student-manipulated models are physical representations of a target phenomenon (Gilbert, Boulter & Elmer, 2000) and are commonly used in undergraduate geoscience courses. Prior studies have focused on courses with small class sizes and do not discuss their implementation in large lecture courses. For example, studies such as Reuss and Gardulski (2001), Frey et al. (2003), or Swope and Giere (2004) described the use of models in laboratory sections or lecture courses for geoscience majors. The small number of students (n < 30) in these courses simplifies distributing the models, addressing student questions, and assessing student learning. In contrast, using physical models in a large, undergraduate, general education lecture course poses logistic and pedagogic challenges that are not present in these smaller courses. Instructor-driven demonstrations are one commonly reported approach for including models in a large lecture course (e.g. Tolley & Richmond, 2003; Harpp, Koleszar, & Geist, 2005); however in these cases the students passively observed the model at a distance but did not actively manipulate the model or observe it from close range. Such lessons also focused on demonstrating a given

concept and did not allow students to test alternate hypotheses or solve problems associated with the phenomenon. Another strategy is to have students act out geologic phenomena (Ponomarenko, 2004), but kinesthetic lessons like this require sufficient room for the students to navigate. If the course is taught in a traditional stadium-style classroom, such an activity may not be practical.

In the geosciences, a small number of studies have reported using student-manipulated models; however none of these papers described the student attitudes towards using the models. Ponomarenko (2004) described a method for using fruit to simulate silica tetrahedra in a physical geology course but did not discuss student attitudes or reactions to using the models. Similarly, Steer, Knight, Owens, and McConnell (2005) described a lesson where students used string and clay models to represent Earth's internal structure. They focused on describing a theoretical framework based on conceptual change and assessing changes in student understanding rather than describing the factors that contribute to successfully implementing student-manipulated models in a large lecture course. In addition, they did not describe the student actions or attitudes towards using these models.

This paper assesses student reactions to using physical models in a large lecture course while identifying difficulties that can arise when using this pedagogical technique. We also describe the nine models we developed and present observational and interview data that assess student attitudes towards using the models. The paper concludes with several lessons learned from our experiences in developing and implementing student-manipulated models in a large, undergraduate, earth science course.

Methodology

Classroom Setting

For the present study, we developed nine models for use in a large (160 students), non-major, introductory earth science course at a large (student population = 24,000) Midwestern university. A majority of the students from these classes were freshmen who had not declared a major, so this earth science course was typically their first undergraduate science experience. Comparisons of student populations among classes indicated no significant demographic differences based on gender or race. Student scores on the ACT and SAT college entrance exams also did not significantly vary between classes.

The course consisted of three 50-minute lecture periods per week with no lab component and was taught using a variety of active-learning techniques. The classroom was a typical lecture room with fixed seating arranged in rows so all students had an unobstructed view of the instructor. The nine classes included in this study were taught by two geology faculty members with over eight years of experience in implementing active learning techniques in this course. Early in the semester, the students from each class were placed in designated four-person work groups that were responsible for recording their understanding of key concepts on daily worksheets or completing in-class learning activities. A typical class utilized a peer instruction pedagogy (Mazur, 1997),

where students listened to a short lecture (≈ 10 minutes) before answering conceptually-based questions using an electronic personal response system ("clickers"). If more than 25% of the students failed to correctly answer the question, the students discussed the question within their student work groups before answering the question a second time.

During most class sessions the students also completed at least one in-class activity requiring them to analyze, synthesize, or evaluate information about the target concept. For example, over the course of the semester the students evaluated a city's vulnerability to earthquake hazards, graphed data on decaying radioisotopes, and completed a Venn diagram comparing plutonic and igneous rocks. Consequently, the students from this study did not passively listen to an instructor elucidate the main points from the text during a 50-minute lecture; rather they experienced an active-learning environment aimed at fostering student interaction with the key concepts from the course. Within this context, all of the model activities described below were completed by the designated student work groups.

Model Development

During the 2006-07 academic year, nine models (Table 1) were developed and implemented. Each model focused on a single concept and provided a physical, hands-on opportunity for the students to confront their preconceptions and modify their understanding as needed. To ensure maximum student use, the models contained few misleading features, were easy to construct, required minimal instructions, and were relatively inexpensive. The final design of each model resulted from discussions by the authors over common student misconceptions and by brainstorming possible methods of representing each phenomenon covered in the course. Once a design was chosen, the authors continually evaluated and improved either the physical design or the implementation of each model. This iterative revision process greatly improved the models' effectiveness in the classroom. Based on these discussions and our experiences implementing the models during the 2006-2007 academic year, eight models were selected (Table 1) for ongoing evaluation during the fall 2007 semester. We redesigned another model (plate kinematics) to accommodate the dynamic nature of moving tectonic plates and developed a ninth model (fronts) to address observed student difficulties with that topic. The final nine models illustrated concepts from astronomy (seasons), plate tectonics (plate kinematics, subduction zone earthquakes), rock properties (igneous rocks, sedimentary/metamorphic rocks), and geologic time (relative age, half-life) as well as weather (fronts) and climate change (tree rings).

Table 1
Nine Hands-On, Physical Models Chosen For In-Depth Evaluation

| Model Name	Model Description	Primary Concept
Earth Seasons*	Foam ball on a wooden stick and a flashlight	Insolation variation with latitude and causes of summer and winter
Plate Kinematics*	Two strips of paper labeled as tectonic plates fitted on a piece of cardstock containing three slots	Demonstrate the movement of plates from mid-ocean ridges to trenches and the processes that occur at each plate boundary.
Subduction Zone Earthquakes*	A transparency stapled to a legal-sized sheet of paper	Demonstrate that earthquakes occur on one side of the trench and magnitudes do not systematically vary with depth
Igneous Rocks*	Representative samples of granite, rhyolite, gabbro, and basalt	Identify differences in texture and composition and relate to volcanic processes
Sedimentary and Metamorphic Rocks	Representative samples of sandstone, limestone, halite, and gneiss	Relate textural observations to processes of formation
Relative Age	Plastic landform models with layered cross-sections drawn on each side of the model	Application of Steno's Laws (superposition, original horizontality, cross-cutting relations)
Half Life*	Fifty small washers painted gold on one side	Demonstrate the characteristics of half-life
Fronts	Two transparent strips labeled "cold" and "warm" front plus a paper with three printed cities locations	The shape of each type of front and the relationship between observed weather patterns and the passage of fronts
Tree Rings*	A section from a pine board	Extension of the climate record into the past

* Model descriptions available on the SERC website
(http://serc.carleton.edu/introgeo/demonstrations/examples.html).

Model Descriptions

This section briefly describes each of the nine models (Table 1) used in the study and summarizes the target concepts for each lesson. Figure 1 also shows each model. The models are also listed in order that they were taught in our earth science course. Descriptions and templates for six of these models can be downloaded from Carleton College's Science Education Resource Center (SERC) website (http://serc.carleton.edu/introgeo/demonstrations/examples.html).

Seasons model. We developed a three-dimensional model that allowed students to explore the Earth-Sun system and model variations in solar insolation and Earth's orientation in space to better understand the origins of the seasons. The Seasons model consisted of a four-inch foam ball purchased from a local craft store, a bamboo skewer, a toothpick, and a small, inexpensive flashlight (Figure 1). The equator, the tropics, Australia, and the location of our university were annotated on each globe using different colored markers. Students used the materials to explore the Earth-Sun system by completing three activities by varying Earth's tilt angle and latitude and observing the differences in solar insolation. Students also simulated Earth's orbit around the Sun and related their observations to the progression of the seasons. Gray, Steer, and Owens (2010) and the SERC website provide a detailed description of these activities. (http://serc.carleton.edu/introgeo/demonstrations/examples/seasons.html)
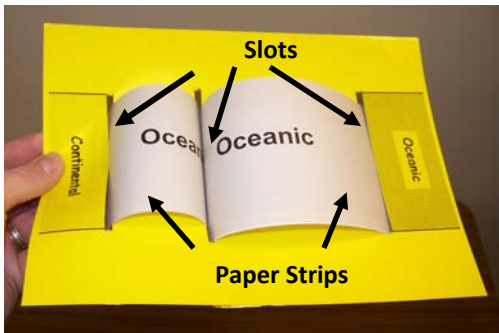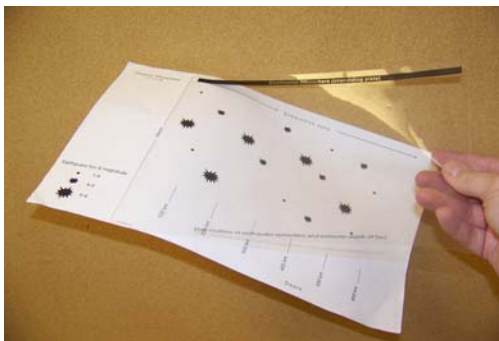
Seasons
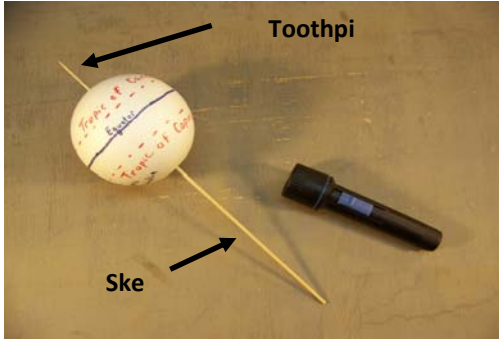
Half Life

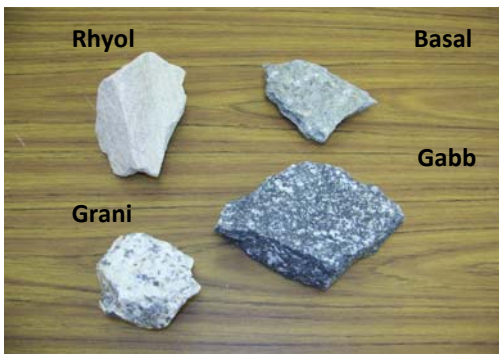**Plate Kinematics**

Tree Rings

Subduction Zone Earthquakes
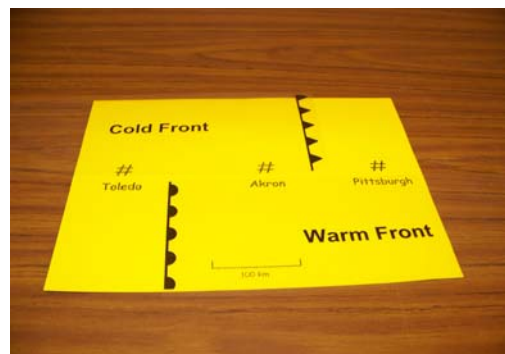
Relative Age

Igneous Rocks

Fronts

Figure 1. Photos illustrating eight of the models described in this paper.

Plate kinematics model. The Plate Kinematics model (Figure 1) physically modeled basic plate kinematics, illustrated oceanic topographic features supporting the theory of plate tectonics, and modeled an active subduction zone. The model consisted of a laminated sheet of cardstock containing three slots. The slots modeled a mid-ocean ridge and two trenches with paper strips made from legal sized copy paper representing the moving lithospheric plates. One set of strips labeled "Oceanic" was intended to model oceanic lithosphere. A second set of strips labeled "Continental" and "Oceanic" represented plates with both oceanic and continental lithosphere. Students were shown how to thread the strips through the slots and model the dynamic aspect of plate motion. The students used erasable markers to label features such as the mid-ocean ridge, trenches, and subduction zones, as well as the locations of volcanoes, earthquakes, high heat flow, and relative lithospheric ages. During lecture, the instructor used the model as a reference point when posing discussion questions pertaining to plate features, such as the location of the oldest or youngest oceanic lithosphere, or plate dynamics such as the formation of new ocean basins during continental rifting. Templates for this model are available at http://serc.carleton.edu/introgeo/demonstrations/examples/plate_kinematics .html.

Subduction zone earthquakes model. The Subduction Zone Earthquakes model was developed in response to our observation that students had difficulty interpreting maps that showed real-time earthquake data. Specifically, students could not predict earthquake distributions at subduction zones, often confused the terms epicenter and focus, and were unable to select proper earthquake magnitude distributions at various plate boundaries.

These issues were addressed by developing an interactive model that allowed students to vary plate subduction angles, explore spatial patterns and observe that earthquake magnitude was not related to depth. The model consisted of a legal-size (11x14) sheet of paper representing the subducting plate and a clear transparency sheet representing the overriding plate. The paper was annotated with a depth scale, a trench, and symbols for three different earthquake magnitudes (labeled small, medium, and large). The transparency was stapled to the paper at the trench. Students simulated a subducting plate by holding the transparency level while allowing it to drop downward. By holding the paper at different angles, the students could test the effect of subduction angle on the distribution of earthquake epicenters. Student groups looked vertically through the transparency to mark the epicenters on the overriding plate (transparency). Once the epicenters were marked, students considered how the width of the Benioff-Wadati Zone changed if the subduction angle were increased. Students then identified and labeled the new epicenters using a different colored marker. Templates for this model are available at http://serc.carleton.edu/introgeo/demonstrations/examples/subduction _zone_earthquakes.html.

Rock models. The earth science course described in this study did not include a lab component, so students did not have an opportunity to interact with actual rock samples. The models for Igneous Rocks and Sedimentary/Metamorphic Rocks addressed this issue by providing an opportunity for students to observe and touch representative samples of the three major rock types. Students also used the models to evaluate their

understanding of basic rock-forming processes. Both models consisted of a bag rocks representing the major categories of rocks. Students were tasked to sort the rocks according to their defining characteristics. For example, the students sorted four igneous rocks according to their color and texture and related those observations to the magma cooling histories for each rock name. Once the sorting activities were completed, the instructor quizzed the students by asking them to find a particular sample such as "a low-silica, volcanic rock" or "a clastic rock". Unlike the other models, these activities did not explicitly provide an opportunity for students to explore their own hypotheses. A description of the Igneous Rocks model is available at http://serc.carleton.edu/introgeo/demonstrations/examples/26478.html.

Relative age model. This model consisted of a commercially available plastic landform illustrating the relationship between landscape geomorphology and stratigraphic relations of the underlying strata. Students were directed to a cross-section that illustrated Steno's laws of original horizontality and superposition, and were asked to determine both the sequence of events that formed the observed strata as well as the relative ages of the rock layers. The students then applied their understanding of these principles by interpreting the sequence of events on diagrams printed on a worksheet.

Half-Life model. This model used small hardware washers to simulate radioactive decay. One side of each washer was painted gold and students were instructed to place the washers in a box and shake it a set number of times (typically five times) after which they removed all of the gold-colored washers and recorded the data on a table. The process was repeated until all of the washers were removed from the box, at which time the students graphed their results and answered questions pertaining to the calculation of a substance's half-life. They also used a known half-life to calculate the age of a hypothetical rock sample. The worksheet and instructions for this model are available at http://serc.carleton.edu/introgeo/demonstrations/examples/26461.html.

Fronts model. This model provided students with an opportunity to explore the relationship between the type of atmospheric frontal boundary (cold versus warm front) and front shape (steep versus shallow respectively). The model consisted of three local cities printed on a sheet paper and two strips of clear transparency film. The distance between each city represented approximately 150 km and the transparencies were printed with symbols representing warm and cold fronts. The students were instructed to properly orient the model fronts to simulate the shape of each boundary. The students then predicted the types of weather that would be present in each at each city and moved the fronts across the map and determined the changes in weather for each city. During the subsequent lecture, the instructor used the geometry of the fronts as a scaffold for a discussion on front-related precipitation.

Tree Rings model. The Tree Rings model consisted of a small pine board containing the center of the tree, 30 to 100 rings, and noticeable variations in the width between the rings. Students were instructed to determine the minimum age for the tree as well a first-order approximation of changes in climate where the tree had lived. This activity provided a springboard for discussing the factors controlling tree growth and the establishment of the prehistoric climate record and reinforced the concept that Earth's

climate is a dynamic system that continually responds to environmental inputs rather than a static, unchanging phenomenon. A description of this model is available at http://serc.carleton.edu/introgeo/demonstrations/examples/26483.html.

Model Implementation

Published descriptions of using in-class activities in conjunction with student-manipulated models have focused on smaller laboratory or majors courses (e.g. Frey et al., 2003; Swope & Giere, 2004). Distributing materials and monitoring student learning in these settings is easier than in a large lecture hall. By using the previously established four-person work groups, we minimized the time needed to conduct each model activity and did not have to use class time for students to organize themselves into work teams. We further reduced the amount of class time needed to conduct the model activity by distributing the materials before class started. Placing the materials at the front of the room near the instructor and asking a representative from each group to retrieve the items was more efficient than placing the items near the entrance and handing out the materials as the students entered. In the latter scenario, groups often collected more than one set of materials which then had to be redistributed so all groups could have one model to work with. At the end of the class session, students returned the materials to the appropriate storage container at the front of the room. This procedure allowed for a smooth transition at the beginning and end of each class and required minimal effort on the part of the instructor.

The nine student-manipulated models were interspersed throughout the semester. On days when we did not use a physical model, the students still experienced an active-learning environment by electronically answering formative assessment questions, observing an instructor-driven demonstration, or completing an in-class activity. During a typical class that used a model activity, the instructor would start his lecture with a review of the previous day's material followed by an initial presentation of the current topic. At an appropriate time, the instructor would project onto the screen a set of instructions for the students to follow, read the directions out loud, and add any additional comments to help the students understand the task set before them. Each model activity focused on students making observations and using that data to draw conclusions about the target concept. For all nine of the models described in this paper, we gave the students a task to complete, however, some of the activities such as the Seasons model and Subduction Zone Earthquakes model allowed students to explore their own questions. The entire model activity typically took five to ten minutes to complete.

As the students began working on the assigned model activity, the instructor circulated around the room and answered student questions or verified that the students were making the desired observations. When the course graduate teaching assistant also moved around the room, every group of students could be visited in just a few minutes. For groups that needed assistance, the instructor directly answered questions on how to complete the assigned task but did not directly answer questions concerning the "correct" answer. In some classes the graduate students did not circulate around the room and answer student questions, in which case not every group had an opportunity to clarify lingering questions or correct inaccurate uses of the model. When interviewed, students

who did not have regular contact with an instructor or teaching assistant commented that they would have made better use of the models had they been able to discuss the activity with the instructor or graduate student.

Initially the students appeared to find the materials distracting, but this issue quickly faded away. During our first model activity (the Seasons) students often twirled the models while listening to the instructor, but for subsequent models the students typically placed the materials on their desk or on the floor and rarely played with the models until instructed to complete the model activity. We interpret this change in student behavior as students realizing that the modeling process would be instrumental in their understanding of key course concepts. By the second model activity the students were more accustomed to using models in the classroom and may have understood the pedagogical impact on their learning. The instructors emphasized this point by explaining how the model activities would help many of the students better understand the material covered in class.

The instructors of this course also experienced an adjustment period during which they learned how to best implement each model. For example, fewer students (16%) from the first class that used the Seasons model correctly answered ConcepTest questions than students in a control class from the same semester; however students from all subsequent classes who used the model demonstrated greater learning gains when compared to students in the control classes, who did not use models. Gray et al. (2010) found that when responses from this initial model class were excluded, students who used the Seasons model correctly answered 11.5% more questions with an effect size of d = 0.48 (implying this finding was of moderate importance). They concluded that the low scores from the ConcepTest questions associated with the first model class were due to factors pertaining to instructor implementation of a student-centered, manipulative model in a large lecture course. Classroom observations suggested that some of these factors included explaining the educational benefit of completing the model activity, providing clear instructions, asking the students to complete one task at a time, and demonstrating the proper use of the model after the students had time to use it.

Model Evaluation

We collected data on student attitudes towards the models and the associated in-class activities by interviewing a random sampling of students. After two semesters of observing students and modifying the models, we interviewed a total of 60 students during the Fall 2007 and Spring 2008 semesters. These student participants were randomly selected from the five classes taught during those semesters and represented a typical cross-section of the course's student body. Participants were compensated with a $10 university gift card and asked to complete a 30-minute semi-structured interview. The interviews began once the students had used the first model (the Seasons model) and continued throughout the semester. During the interview, the students described their initial reactions to the models and their current opinion of the modeling process. We also asked students to provide what they liked and disliked about specific models as well as the model activities in general. Nine students were randomly selected to return during the same semester for a second interview on a second model, and students at the end of the

semester were asked to summarize their experiences over the entire term. All interviews were recorded and transcribed for subsequent analysis.

To investigate the student behaviors when using the models, we directly observed the students using the models. The observations were collected by a cadre of trained observers who each monitored a different student group and recorded the student interactions with that particular model. The observers were initially recruited from a pool of pre-service secondary science teachers, but in subsequent semesters, geology majors and students who had previously earned an A in the course were used to bolster the number of observers present in each class. Three, one-hour training sessions were used to explain the goals of the project, answer questions, and provide guided practice in recording detailed observations. These practice sessions included the use of short segments from films showing teachers instructing their students. After each segment, the observers shared what they had written and discussed how they had collected the data. The researcher provided continual feedback on the strengths and weaknesses of each person's report and listed suggestions on how to take more comprehensive notes. Before collecting data on a model activity, each observer was required to attend at least one class session and practice recording observations in the classroom setting. Their reports were subsequently typed and evaluated by one of the researchers, and additional suggestions were made on how to improve the quality of the data being recorded. A common error included listing inferences about student cognition as observations such as "Student #1 did not understand the question" instead of "Student #1 stared at the question and did not provide an answer." Throughout the semester the observers continued to receive feedback on ways of improving their observation reports.

The data for this paper comes from nine course sections taught between the Fall of 2006 and Spring of 2008 with at least two sections taught in each term. Because we infused active-learning strategies into this course, we did not designate an entire section as a permanent control section. Rather, over the course of each semester, we rotated the designation of control and treatment among all of the sections offered that term so students were never in a control section for two consecutive models. On days when we taught using one of the nine models, students in both sections experienced the same lectures, however, the students in the control sections completed an additional active-learning activity covering the same concept as the corresponding model activity and lasting approximately the same length of time. Examples of alternate activities included additional ConcepTest questions or completing summary questions on a review sheet.

Results

Student Interviews

During each interview, the students were given multiple opportunities to describe their attitudes towards the model activities in general as well as their opinions on specific models. Using a constant comparative analysis of the interview transcripts (Glaser, 1965; Glaser, 1998), we identified those student responses that described their attitudes or evaluations of the models or model activities and looked for emerging patterns or themes. In the final analysis, three common themes emerged from the data (attitudes, attention,

and improved learning). Each category provided a glimpse into what our students were thinking during the lesson and suggests what factors influence their attitudes towards this type of active-learning pedagogy. All names throughout the paper are pseudonyms.

   Student attitudes. The data from the student interviews suggest that most of the students preferred using the models over listening to a lecture. At some point during the interview all 60 students discussed or mentioned their attitudes of the models and model activities. These responses were coded as indicating a positive, negative, or neutral attitude towards the models or model activities. Fifty students (83%) stated that they preferred using the models over the lecture (Table 2). Examples of positive comments (Table 3) included explicitly stating that the student liked or preferred the models, the student found the model helpful or useful in learning the target concept, or they preferred both the model activities and the active lecture format used in throughout the course. Four of the remaining students (7%) stated that they preferred the lecture

Table 2
Summary of Student Attitudes Towards The Models

Positive	50
Explicitly Stated A Positive Preference	34
Stated Model Was Helpful	7
Stated Both Model and Lecture Helpful	9
Neutral	6
Lecture	4

Note. One student gave conflicting responses for different models, and another student was unsure of her view on lectures. Both were categorized as "Neutral".

Table 3
Examples of Student Evaluations of the Model Activities

Characteristics	Examples
Positive (50 students)	
Explicitly stated a positive attitude towards the models	"The model would help out a lot more than the lecture."
Cited examples of how the models were helpful	"I liked using the rocks because I could see what he was talking about."
Liked both the models and the lecture	"Models are nice and usually his lectures are fun. A little bit of both."
Neutral (4 students)	
Explicitly stated a neutral attitude towards the models	"I don't know...he could've just did them on the screen too." (Referring to images of the igneous rocks)
Gave positive and negative examples from multiple models	*Fronts:* I don't know...he went really fast and most of the people around me were just really confused… *Sedimentary Rocks:* It just gives you more of a visual aid.
Gave a positive and negative evaluation of the models	For this class, it's fairly elementary stuff, especially since it's my fourth year and this is a freshman level class... So I could get by with just lecture in this class, but if it was something that was more difficult for me, I'd probably like to have the models to better explain things."
Negative (6 students)	
Explicitly stated a negative attitude towards the models	"Honestly probably just the lecture."
Cited examples of how the lecture would have been helpful	"I would like to have more notes to actually write…Because that's how I learn. By writing, rewriting…"

over the model activities and six students (10%) gave answers that suggested a neutral attitude towards the models.Three students reported that they both liked and disliked the models. Given that the three students provided conflicting opinions, they were classified as having a neutral overall opinion about the models, and their responses suggest that some of the students who preferred the models over lecture may have held a different opinion on other models. During the course of the student interviews, five students gave a negative evaluation of the models; however these comments typically centered on how the models were implemented rather than dissatisfaction with the models or model activities themselves. Two of the students commented that they preferred lecture over the model activities because they learn best by taking notes and could use the notes for later study. Similarly, two other students noted that the dynamics within their student work-groups interfered with their understanding of the model activity whereas listening to a lecture did not require them to depend on other students. For example, Patti noted that:

> Patti: There's people all around you saying 'This is that' [referring to details of a model]… and it just gets confusing."

The negative comments from the fifth student were directed towards a specific model (the Half-Life model) rather than the model activities in general. In this case, he felt that the model did not help him understand radioactive decay. Besides the direct evaluations of the models, some students who gave positive evaluations of the models also provided ways in which the models failed to work or could be improved. These negative descriptions tended to focused on how the models were implemented in the class rather than how the models facilitated the comprehension of the target concept. For example, Gayle lamented that,

> Gayle: He [the instructor] doesn't get around to the whole class to correct what everyone's doing. And when he's trying to hold it [the model] and demonstrate what's going on, and I'm in the back, I can't really see what's going on.

Her comments illustrate the need for the instructor to formatively assess every student group. In a large class, this may require a student assistant who can visit some of the groups and ensure that everyone understands how to correctly use the model. Gayle's comments also illustrate the need to provide a visual aid that is large enough for all students to easily see. For the Seasons model we used a larger version of the student model to demonstrate the correct way to position the model, and for the rocks models, we projected images of the models on the screen at the front of the room.

Another negative criticism included a desire to have clear, concise directions. Students noted that they struggled to understand how to correctly thread the Plate Kinematics model or set up the Fronts model the first time they used it. Sharon explained why good instructions are important when she said:

> Sharon: It doesn't matter how good the model is, if you don't know the answers, if you don't know how to use it, then it's really no help at all.

We consider comments like these to represent the fact that implementing a new pedagogy such as this is a learning experience for the instructor as well as the students. We addressed this issue by modifying our lectures to include clear directions that asked students to complete a single task. For example, the first semester we implemented the Plate Kinematics model, students struggled to properly thread the model. Once this happened, their attention shifted from understanding the underlying concepts to correctly completing the model task. In subsequent semesters, the instructors gave explicit instructions on how to thread the paper, projected an example on the screen, and modeled the behavior themselves. Observations from the subsequent classes suggest that few students struggled to understand how to properly thread the model and interviews with those students did not contain negative comments regarding how to thread model.

Improved attention. When interviewed, the students cited an improvement in their attention and an improved ability to focus on the learning objective as one reason why they preferred the model activities over a lecture. These students noted the difficulty in concentrating on a lecture for fifty minutes. This attitude was exemplified by Rebecca and Diane.

> Rebecca: If you're just sitting there listening to somebody, you get distracted easily, at least I know I do. I start thinking about stuff I need to do when I get out of class, and you don't really pay as much attention. But if you have it [the model] right there in front of you, and you're supposed to be putting it together or marking on it, you have to give your attention to it [the model].

> Diane: It's better than just sitting there, having someone drilling knowledge into you with a monotone voice and you're not listening and your mind's going to wander, probably ten minutes into the class.

Their comments suggest that the models may provide a focal point for understanding the content being presented by the instructor. Using the models may also provide a change of pace to the lecture that reenergizes the student. In addition, 34 of the students mentioned that they liked the "hands-on" nature of the activities, and students like Ben even stated that the kinesthetic nature of the lessons contributed to his improved attention.

> Ben: To me it's always helped me to be more hands-on. It helps me pay better attention if I'm actually sitting there with the object in front of me compared to have just seen a picture or just hearing about it [the topic].

These are interesting comments in light if the fact that every lecture included active learning strategies such as peer instruction, personal response systems, and in-class activities, each of which were intended to promote conceptual understanding. We speculate that inserting our model activities in a traditional lecture would have an even larger impact on the students by providing a focal point to the lecture and giving students an opportunity to apply the content knowledge under discussion.

This conclusion is ironic given that every class session, including the non-model lectures, contained active-learning pedagogies such as ConcepTest questions or in-class group exercises that also divided the class into smaller units. It is possible that the model activities motivated students to pay attention during the class session because they were a novel activity. This is interesting because every class session contained a novel learning environment including use of the peer instruction pedagogy and in-class activities. For example, the in-class activities and electronic formative assessment questions ("clickers") are quite different from a traditional lecture-only course. It is possible that by the time the students were interviewed, they may have viewed these active-learning techniques as a routine part of the class whereas the model activities were seen as a new and different classroom experience.

Improved student learning. The students also claimed the model activities were a tool that improved their learning or helped them recall information when taking the exam. These students reported that using the models gave them a common frame of reference from which they could organize information and terms pertaining to the concept or correct an incorrect understanding of the target phenomenon. For example, Rick described how the Seasons model corrected a common misconception when he stated that

Rick: It just helped me understand the fact that it's not the distance from the Earth from the Sun, it's the tilt of the axis.

Similarly, Virginia noted how the Seasons model helped her recall the information on the exam.

Virginia: Well when we did the Sun [Seasons Model], at my test I'm actually sitting there going, 'It [the Earth] revolves this way.' So that was helpful because I actually sat there doing it.

This opinion was not limited to the Seasons model. Kevin noted that the Subduction Zone Earthquakes model helped his group understand the difference between an earthquake's focus and epicenter.

Kevin: It's [the model] good for distinguishing between the epicenter and the focus of the earthquake. And also to distinguish the difference between the different sizes and depths

Similarly, Craig explained how the Fronts model helped him remember how warm and cold fronts have different shapes.

Craig: The [Fronts] model helps me understand a little bit more, like the model is the reason I remember why the warm front is less of an incline than the cold front.

Besides serving as an aid to understanding the target concepts, the students also reported that the models acted as a visual aid that could be recalled to answer exam questions. Without being directly asked, ten students commented how the models helped them recall information for the exam. Lisa summarized this when she noted that:

Lisa: Because it just puts a picture in my head, and then when I go to take the test, I can see it [the model] in my head.

The students cited the Seasons model more than any other model as being helpful on exams. This model may have been particularly helpful because it addressed a well documented set of misconceptions (see Vosniadou & Brewer, 1992) and could be mimicked by hand gestures during the exam. Virginia's earlier quote refers to this process.

It is worth noting that one student (Gayle) stated that the models were helpful in class but not on the exam.

Gayle: I thought that using them [the rocks models] in class was helpful, but then when I got to the test, I didn't do so well, because having them in your hand is one thing, but then there's so many different types of rocks and some of them look similar and some of them look so different. Like the ones that are so different you can remember, but the ones that kind of look alike I couldn't remember.

Gayle was interviewed near the end of the semester and identifying rocks had been covered approximately two months earlier. Her comments suggest that she never mastered the skill of identifying the texture and color differences between high-silica and low-silica igneous rocks. This lack of comprehension may have led to her negative evaluation of the model in terms of helping on the exam, but note that overall, she provides a positive evaluation of the model activities in general.

From the interviews we conclude that the most students believed that the model activities helped them understand the target concepts and that several students recalled the experiences when taking the subsequent exam. The models appear to have created a common experience that allowed the students to interact with the target concept. Then when asked to recall the information for the exam, these students apparently used those experiences as anchors upon which they could attach their new understanding. This process was summarized by Eric and Doug.

Eric: I think people can put a picture with a description, so it was easier to recall which rock type someone was talking about or just describing.

Doug: It [the model] lets you interact, and as you're learning about it, you show it to yourself, to see what it's doing. I mean it's a nuisance to walk to the front of the room to get them, but it was worth it when you get to sit there and use it. And then when you get to the test and the questions are related to the models, you can see a picture on the test and you can relate it to the volcano model or the relative age model. If they related to it, you can see the same kind of picture and just follow what you did before.

In-Class Observations

The in-class observations confirmed many of the findings from the student interviews and further suggest that the level of teamwork within each group of students may have contributed to the effective use of the models. Over 80% of the students interviewed said that the models helped them learn the material better than our typical active lecture using peer instruction. In-class observations found that students used the models (for example the Seasons and Plate Kinematics models) throughout the lecture, even once the model activity was completed. Gray, et al. (2010) noted that students oriented the Earth model to mimic the instructor's use of the larger demonstration model. Students also used their models to duplicate illustrations from the textbook. When asked to answer a ConcepTest question on the seasons, students often used the Seasons model to recreate the scenario given in the question. Similar behaviors were observed for the Plate Kinematics model.

Besides using the models to recreate the information presented by the instructor, many students used the models as visual aids to explain the target concept to their peers. For example, a common problem faced by our students was correctly identifying the number of tectonic plates present on a simplified tectonic map. We observed groups where one student would hold the Plate Kinematics model and explain how the plate boundaries could be used to determine the number of plates. Similarly, Gray et al. (2010) noted how one student would often use the Seasons model to explain to his or her peers how an increase in the tilt angle would increase the average summer temperature and decrease the average winter temperature. It is possible that these episodes of peer tutoring may have contributed to the generally positive student evaluations of the model activities.

The in-class observations also confirmed that clear, concise instructions decreased student confusion and increased student participation. During those classes when a model was first used, we observed students asking questions on how to complete the task. When this happened, the students appeared to focus more on completing the task than understanding the underlying concepts. But in subsequent classes after the model and/or the instructions had been modified to improve the clarity of the assignment, the students asked fewer questions regarding the use of the model. For example, in the first class to use the Subduction Zone Earthquakes model, many of the observed groups were unsure how to complete the task and asked neighboring groups, the instructor, or the teaching assistant to clarify the directions. Similarly, students in the first class to use the Plate Kinematics model were unsure how to thread the strips of paper to model the oceanic plates. In several groups, the students stopped discussing the model and focused entirely on "following the directions." In a later class, the instructor modified his directions by showing the proper way of assembling the model. In those classes, students then used the model to quickly complete the assigned activities and were more prone to refer to the model in their discussions.

Not all of the groups collaboratively used the models. Instead of collaborating together, observers reported that some groups had one person who used the model while the other members of the work group either watched or ignored the model. These cases were rare but suggest that group dynamics may moderate any learning effects generated by participating in a model-based activity. Data from the student interviews support this assertion. Students reported that they feared being placed with group members who did

not want to participate in the assigned activities. Those students who said they liked their groups belonged to groups whose members consistently attended class and actively participated in all of the in-class activities. A few interviewees reported communicating with group members outside of class to set up study groups. Students who did not prefer working in the groups either were upset that they could not choose to work with their friends, or belonged to groups where the other members did not regularly attend class, or were unwilling to participate in the model activities. Further research may identify common factors among groups that collaboratively work to complete the task compared to those groups in which members do minimum work or ignore the task altogether.

Discussion

The data from this project suggest that our physical, manipulative models helped students form enduring mental images through personal interaction that was self-developed (Helstrup, Cornoldi, & Debeni, 1997). Students commented that the model activities broke up the routine of listening to the instructor's lecture and focused student attention on the key concepts presented in class. In particular, students used the models during the lecture and when answering ConcepTest questions. In addition, the students were able to explore alternate hypotheses such as what would happen if Earth had a 90 degree tilt or how the width of earthquake epicenters would change if the subducting plate were oriented at a steeper angle. During the interviews, students explained how the models provided a mental image that stayed with them long after they had forgotten the details of the lecture, and it was this image that helped them answer the exam questions. Perhaps these students were able to recall details of each model days or weeks later because they personally interacted with each model and explored topics they found interesting.

Other factors that may have influenced the results include the type of learning environment as well as the abstract nature of the topics. The classes observed in this study experienced an active-learning environment that encouraged concept formation. All of the students were placed into groups where they discussed the key concepts from that class, evaluated ConcepTest questions, and completed in-class worksheets. As such, when the students in our study served a control group, they still experienced a student-centered and assessment-based teaching environment rather than a traditional instructor-centered environment. In addition, the topics covered in this study were all complex, abstract concepts that are not easily grasped by the novice learner. Our students may be been unaware of the phenomenon (e.g. they may not have known that magmas can cool at different rates) or harbored deeply seated misconceptions (e.g. Earth being closer to the sun in the summer than in the winter, Vosniadou & Brewer, 1992). Using these models appear to have directly addressed many of the common inaccurate conceptions held by today's students, yet the models' greatest value may have been as a formative assessment tool used by the instructor. By monitoring how the students manipulated the models, the types of questions they ask, and the answers they provided, the instructors could identify the most common misconceptions for that class and directly address them in the subsequent lecture.

Lessons Learned

The bulk of the data indicated that these models can provide an alternate pathway for students to learn the target concepts by scaffolding student learning, however instructors need to take the time to consider the best way to implement hands-on models into their own classes. The experiences gained in this study suggest at least six points that should be considered when implementing models in a large lecture class.

Lesson 1: Focus on One Concept

The most effective models were simple representations of one concept rather than a complex model involving multiple concepts. In the examples discussed here, the subduction zone earthquake model was effective because it targeted just one idea. The Seasons and Plate Kinematics models covered multiple concepts, yet the lesson was broken into discrete sections where each concept was taught separately with the model used to illustrate one concept at a time. If a model activity addresses more than one concept, student confusion or cognitive load can be minimized by dividing the activity into smaller units that each focuses on a single concept.

Lesson 2: Use Simple, Straightforward Directions

Using clear, concise instructions at the beginning of the activity allowed students to focus on the concepts rather than the steps in the activity. Data from both the classroom observations and student interviews indicated that when the students struggled to understand the directions, their attention to the model decreased, and their attention shifted away from the concept under consideration and focused on completing the task at hand. When the instructions addressed common problems expressed by the students (such as assembling the Plate Kinematics model), students tended to focus on understanding the underlying concepts and did not become easily frustrated or confused over how to use the model.

Lesson 3: Explain the Model and Why it is Being Used

One common problem encountered when using models in the classroom was the tendency for students to assume incorrect attributes of the model. For example, textbook illustrations of Earth's rotational axis typically show a line representing the axis passing through the planet. The Seasons model used a skewer and toothpick to represent this axis. However, during one interview, a student asked if a rock pillar physically existed at the North Pole, which suggests that the toothpick at the top of our model used to illustrate Earth's rotational axis may have reinforced the misconception that Earth's axis is a physical object rather than an intangible mental construct. Reminding students that the models simulate only a portion of the target Earth system is one way to prevent the formation of inaccurate conceptions. Students should be encouraged to think about both the strengths and weaknesses of the models.

Students also need to be reminded that using such models can help them remember key aspects of the concepts. Providing such a reminder reinforces the utility of the model and describes a personal benefit for the student as evidenced by student

interview data. When our students were initially given the first model of the semester (the Seasons model), some of them played with the model but these behaviors were discontinued once the instructor explained how the model activities would help each student better understand the material. Similarly, during the interviews, students often noted that they were unsure why the instructor had distributed the models, but once the students understood the purpose of the model activities, they accepted the practice and eventually formed a favorable opinion towards the models.

Lesson 4: Expect Some Student Resistance

Participating in a hands-on modeling activity in a large lecture class was not a common experience for most undergraduate students. Classroom observations showed that some students did not initially engage with the models or inappropriately played with them during the lecture. This was especially true for the first model used in the course. Other students did not actively participate in the model activities but watched from a distance as other students in their work groups manipulated the models. At first, these actions may be perceived as student resistance towards using the models; however, it was our experience that once the modeling activities began the students actively participated in the exercise. After repeated use of the in-class modeling activities, the students accepted these learning activities and eagerly engaged. Preference for a traditional didactic lecture may reflect a desire to remain within a familiar pedagogy that has worked for them in the past, but our data suggest that continued use coupled clear instructions and formative feedback will eventually reduce or eliminate such resistance.

Lesson 5: Use Student Groups

One theme that emerged throughout the observations and interviews was the importance of student-student discussions in fostering conceptual understanding. Students reported in interviews that they studied outside of class with group members or felt more comfortable asking someone from the group for help rather than revealing their lack of understanding to the instructor. While using the models, group discussion allowed those who already understood the concepts to tutor those who did not, fostered quick dissemination of the materials, and shortened the transition time for starting the model activities by eliminating the need for the students to form ad-hoc groups during each class session.

Lesson 6: Expect Revision

Incorporating models in large lecture classes was an iterative process that required multiple revisions. The first time the Seasons model was used, the students struggled to complete the tasks, so the instructions were rewritten for later classes. Initially the Plate Kinematics model used modeling foam, but we noted that the students were still struggling to understand the dynamic nature of plate tectonics, so the model was revised. The process of using physical models in large classes to facilitate learning illustrates how incorporating active learning strategies may take several semesters to perfect (Owens, Steer, & McConnell, 2006).

Conclusions

The data reported in this study indicate that placing students in groups and having them manipulate physical models can increase their conceptual understanding of the material and make the class more interesting. Students were observed using the models as visual tools to scaffold learning by creating a mental image that they took from the classroom and recalled at a later date (e.g. during a test). Perhaps the most compelling evidence came from the students themselves. Students commented that they preferred using the models to just a lecture – even in an active learning environment. As Roger put it,

> Roger: For visual learners, like I am, this is just everything that I can count on. Because I read and I can understand and comprehend it but when I think back, I think about models, not about what I read.

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