The Influence of Students' Understanding of Models on Model-Based Reasoning [1]

Janice Gobert Concord Consortium
Jennifer Snyder University of Kansas
Carolyn Houghton Concord Consortium

For further information, contact: jgobert@concord.org

Abstract

A curriculum unit for middle school Earth Science called "What's on Your Plate?" was designed (Gobert et al, 2001) and implemented in WISE (Web-Based Inquiry Science Education) (Linn et al, 2001). Briefly, the unit and larger research study involved 400 middle school students from California and Massachusetts who collaborated on-line during the 2 week unit.

The unit was designed with two main pedagogical principles: Make thinking visible, and help students learn from one another; both were derived from an inquiry-based framework (Linn & Hsi, 2000).

Within these two main pedagogical principles as a larger guiding framework we designed the curriculum to provide students with rich, iterative model-based activities for students to both learn with and provide criteria for them to critique their peers' work from the opposite coast. Need more here on modeling activities. The goal here was to influence students' understanding of the nature of models in science, etc.

Data from 15 classrooms is described both in terms of the gains students made of their understanding of the nature of models as measured by pencil and paper survey administered both before and after the unit, as well as examples from students' reasoning with their models and critiques of their peers' models.

INTRODUCTION

Current reform efforts seek to improve science understanding of our citizens as a whole by promoting lifelong learning such that knowledge can be integrated across topics in school and applied to real world problems (Linn, 1999), such as understanding scientific findings described by the media. Being scientifically literate includes understanding science content, having scientific process and inquiry skills, and understanding the nature of science, i.e., what is taken as evidence (Perkins, 1986). Thus, in order to address scientific literacy effectively, we need to take into account the factors influencing each of these three aspects of science learning. Specifically, to address understanding of **content knowledge**, we need to take into account the repertoire of models students bring to instruction (Inhelder & Piaget, 1958; Linn, diSessa, Pea & Songer, 1994); to address **process and inquiry skills**, we need to design rich tasks that engage

[1] This research was conducted as part of the Making Thinking Visible project which is funded by the National Science Foundation under grant No. REC-9980600 awarded to Janice Gobert. Any opinions, findings, and conclusions expressed are those of the presenters and do not necessarily reflect the views of the National Science Foundation.

the learners in meaningful ways (Linn, 1999); and, to address **epistemic understanding**, we need to address students' (naive) views about the nature of science (Carey et al., 1995; Grosslight et al., 1991; Smith et al., 1999). More recently, it has been argued that an important part of epistemic understanding also includes students' epistemologies of the nature and purpose of scientific models because the degree to which models can serve as representations of scientific phenomena depends on students' epistemological commitment to a model as an explanatory framework of the scientific phenomena under inquiry (Gobert & Discenna, 1997; Schwarz & White, 1999). Thus, in the present work, students' epistemologies of models is included as a subset of epistemology of science.

The widespread use of technology in schools can provide great potential for impacting science instruction and science literacy (Linn, 1999), particularly if the design of our learning environments and activities engaged therein are guided by pedagogical principles informed by educational research. Despite technology's ubiquitous and ever increasing use in all levels of education, its potential offerings for science understanding, and the recognized importance of embedding technology within the science curricula (Linn, diSessa, Pea, & Songer, 1994), there are a plethora of issues, both theoretical and applied, which are unaddressed in research to date. Two of these key issues which are addressed in this paper are: How can we use the technology effectively to promote deep learning in line with epistemic goals? and How can we identify change in students' epistemic understanding?

Theoretical Framework for Scaffolded Knowledge Integration: WISE and its Pedagogical and Philosophical Principles

One learning environment which was designed to promote integration of science content, scientific inquiry skills, and epistemic knowledge is WISE [2] (Web-based Science Environment) developed by Marcia Linn and her group at UC-Berkeley. WISE is an integrated set of software tools coupled with a project-based framework for middle and high school science curriculum focused around Web resources (Linn & Hsi, 2000). WISE which is based on over ten years of research on knowledge integration is informed by its pre-cursor, KIE (Knowledge Integration Environment, Linn, 1999), and has a suite of tools to engage students in many types of scientific inquiry, including prompted reflection, electronic discussions, evidence sorting and argument mapping, collaborative search for evidence, collaborative design, and analysis and reporting (Linn, 1998b). The four basic pedagogical principles for scaffolded knowledge integration embedded in WISE (Linn, 1999) are:

• *Make science accessible for all students* where accessibility has two meanings: to engage students in problems that they find personally relevant, and to engage students at an appropriate level of analysis and explanation, rather than load them down with abstract scientific models of phenomena which do not readily connect with students' ideas.

• *Make thinking visible*; that is, develop supports that facilitate the representation of students' knowledge and scaffold students' learning processes.

• *Provide social support so that students can learn from each other*, that is, take advantage of the collective knowledge of the classroom and get students to consider their own and others' ideas.

[2] For more information, see http://wise.berkeley.edu/WISE/index.html

• *Promote autonomy and lifelong learning*, that is, engage students in sustained reasoning, develop science process skills, and encourage students to revisit and refine their understanding.

Make Thinking Visible. In the research presented, making thinking visible takes on a different meaning than that which was originally proposed by Collins et al. (1991). Here, we extend the notion of "making thinking visible" to utilize **visual modes** of representation in two ways: 1) engage students in drawing tasks to make their models explicit and use these as knowledge artifacts for both model revision as well as collaborative discourse, and 2) provide students with a set of **dynamic, runnable models** of plate tectonic phenomena. Here, students use the runnable prototypes to visualize dynamic, causal, and temporal processes in order to test, critique, and revise their own models. WISE prompts students to justify and explain their changes in order to reify learning. Prompts to be designed include: "What does your new model include that it didn't before?", and "What does your new model describe or explain that it didn't before?"

Help Students Learn From One Another. In the research presented we sought to facilitate students' understanding of the nature of models by giving them model-based tasks such as those described above, as well as by giving them opportunities to think critically about their peers' models and do formal evaluations of them.

This research on modeling and nature of models fits within a current vein of science education which seeks to promote integrated understanding by use of model-based tasks. In these programs students are either presented with models to learn from (Raghavan & Glaser, 1995; White & Frederiksen, 1990) or they are given tasks which require them to construct their own models (Gobert, & Clement 1994, 1999; Gobert, 1998; 1999; Penner et al., 1997; Jackson, et al., 1994). It is believed that having students construct and work with their own models engages them in authentic scientific inquiry, and that such activities promote scientific literacy, understanding of the nature of science, and lifelong learning (Linn & Muilenberg, 1996; Gilbert, S., 1991; Sabelli, 1994).

Domain Studied

This domain was chosen for two reasons. First, it is an excellent domain in which to investigate students' model building because of the important role that model building and causal reasoning play in understanding the hidden mechanisms, e.g., convection underlying continental drift, earthquakes, volcanoes, mountain formation, and sea floor spreading. Briefly, the theory of plate tectonics states that the outer layer of the earth (the crust) is broken up into slabs (the plates) which move on the partially molten layer of the earth (the mantle) due to the convective movement of hot magma in the mantle (Feather, Snyder, & Hesser, 1995; Plummer & McGeary, 1996). Additionally, it is an excellent context in which to study students' epistemologies of models both because there are many excellent models with which to engage learners in model-based tasks, and theory of plate tectonics is a good example of the dynamic nature of science, how scientific inquiry proceeds, and how a hypothesis can be proposed, discarded, modified, and then redefined, as it was in the case of Wegner's original theory of plate tectonics (Le Grand, 1991). The theory of Plate tectonics has changed our entire concept of earth dynamics in the past 35-40 years; earlier the idea of continental drift rated little more than a footnote in most introductory geology textbooks. As such, the theory of plate tectonics represents a major revolution in earth science (Plummer & McGeary, 1996) because it combines hypotheses about continental drift and sea floor spreading in order to provide a unified explanation of the past, present, and future geographic distribution of the earth's landmasses and oceans (Bencloski & Heyl, 1985). The relatively short time scale over which this theory has evolved, and the dramatic gains made in the theory should engage the students' interest in the topic, and make it more accessible.

Background Research on Students' Epistemology of Models and its Relationship to Reasoning

Since learning in the domain of plate tectonics involves understanding and reasoning with models, a previous pilot study was conducted in order to address whether one's epistemology of scientific models influences the characteristics of the diagrammatic models students construct, and the inferences which are made on the basis of these models (Gobert & Discenna, 1997). The underlying hypothesis here was that students with a better understanding of the predictive nature of scientific models would be better able to construct models and use these to make inferences about plate tectonic-related phenomena. No significant differences were found between those with a more (or less) sophisticated epistemology of scientific models for the understanding the spatial or causal/dynamic aspects of the domain; however, those with a more sophisticated epistemology of the nature of models were better able to make inferences about other causal mechanisms involved in plate tectonics, e.g., convection (Gobert & Discenna, 1997).

PRESENT RESEARCH

The present work builds on and extends my existing research in order to design, test, and refine rich tasks for middle and high school students for learning in the domain of plate tectonics. The unit, "What's on your plate?" was designed using the relevant literature on learning in Earth Sciences, namely, misconceptions of plate tectonics of both the inside structure of the earth and of the causal mechanisms underlying plate tectonic-related phenomena (Gobert & Clement, 1999; Gobert, 2000), and findings about students' knowledge integration difficulties in this domain (Gobert & Clement, 1994). The unit was also designed using the WISE design principles (Linn & Hsi, 2000) which are based on 15 years of research in science education. Lastly, the unit is in line with state frameworks for Massachusetts http://www.doe.mass.edu/frameworks/current.html and California (http://www.cde.ca.gov/cfir/index.html).

The "What's on your plate?" unit the students in modeling activities (the topic of the present paper), in the following ways:

1. Students' Model Building & Explanation of their Models. Students were asked to construct in WISE visual models of plate tectonic-related phenomena; that is, each pair of students drew a model of how mountains are formed (East coast only) while students on the West coasts drew models of earthquake or volcanic eruption. Students were then asked to write in WISE a short explanation for their models with the following prompt "Now that you have drawn your model, write an explanation of what happens to each of the layers of the earth when an earthquake erupts (or a mountain is formed, a volcano erupts)". Once students had done these two steps, they posted their models and explanations for their learning partners on the opposite coast (See Appendix A, Activity 1, Steps 3 & 4 for these tasks).

2.Students' Evaluation and Critique of the Learning Partners' Models. Students read two pieces of text in WISE called "What is a Scientific Model? And "How to evaluate a model?" in order to give them some basic knowledge with which to evaluate their leaning partners' models. Then students were prompted to critique learning partners' models using prompts that were presented in WISE. The prompts include:

- 1. Are the most important features in terms of what causes this geologic process depicted in this model?
- 2. Would this model be useful to teach someone who had never studied this geologic process before?
- 3. What important features are included in this model? Explain why you gave the model this rating.
- 4. What do you think should be added to this model in order to make it better for someone who had never studied this geologic process before?

These prompts were designed to focus students' thinking about models in two general ways: causal mechanisms/processes depicted (items 1 and 3), and the model as a communication tool to learn or reason with (items 2,and 4). Prompts similar to the latter have been successful in getting students to generate rich explanations (Gobert, 1997b; in prep.), and it was believed that they might be successful here as well in getting students to think about how useful a model is as a tool for communication purposes. Once students discussed the evaluation with their in class partner (computer partner), they then posted their evaluation for their opposite coast learning partners to evaluate. (See Appendix A, Activity 6 these tasks).

*3**. Students'Model Revision&Justification***. Students read the evaluation that was written and posted by their learning partners on the opposite coast. They were the asked to revise their models based on the critique from their learning partners as well as the content knowledge they had learned from the unit (the model-based content activities will be discussed next). They were also asked to write a revised explanation for their new models. Lastly, here students were asked to justify their changes to their models in WISE in order to engage students in reflection about how their understanding had changed. Prompts here include:

- I changed my original model of.... because it did not explain or include...."
- "My model now includes or helps explain…"
- "My model is now more useful for someone to learn from because it now includes…."
- "I revised this on the basis of my learning partners' critique in the following ways….
- "I revised this on the basis of the activities in these WISE units….. ".

(See Appendix A, Activity 7 for these tasks).

4. ***Geology Websites***. As part of the unit students do an on-line field trip and are guided to visit multiple USGS websites with current data in order to the differences between the coasts in terms of their mountains, volcanoes, and earthquakes. After each "site visit", students write a relfection note for their learning partners on the oppoiste coast about what they have learned about earthquakes, volcanoes, and mountains on their coast. This reflection note is posted for the

learning partners to read and relfect on in terms of how the data observed differ from that of their own coast. (See Appendix A, Activities 2 & 3 for these tasks).

Students also visit a Plate boundaries website in order to speculate about how the location, frequency, and magnitude of geological events (mountains, earthquakes, and volcanoes) "observed in Activity 2 are related to plate boundaries in the earth's crust. After visiting the plate boundaries website, students are asked to write a Reflection Note with the following prompt: Write one (or two) question(s) you have about plate boundaries or plate movement that will help you better understand why the geologic processes on the West and East coasts are different. Students revisit these questions in a Discussion Forum later in the unit. (See Appendix A, Activity 4 for these tasks; See Activity 8 for where they revisit their questions).

*5. **Dynamic-runnable models**.* These models were designed in line with previous research which has shown that visualization facilitates the understanding of dynamic phenomena (Monaghan & Clement, 1995) and that middle and high school students can understand rich dynamic concepts if provided with the appropriate scaffolds and tools (Jackson, et al., 1994; Ploger & DellaVedova, 1999; Frederiksen, White, & Gutwill, 1999).

Students view and read about the different types of plate boundaries, namely, collisional, divergent, convergent, and transform boundaries in order to begin to think about how the location of and type of plate boundary are related to geological occurences on the earth's crust. Students reify their learning by writing reflection notes about what types of geological events are typical of specific types of plate boundaries. (See Appendix A, Activity 5, Steps 1-7 for these tasks).

Students also visit a model of mantle convection which is accompanied by a text which scaffolds their understanding of the dynamic and causal features of the model by directing their processing of the causal and dynamic information in the model as it "runs". Students write a reflection note to explain how processes inside the earth relate to plate movement. (See Appendix A, Activity 5, Steps 8-10for these tasks).

Lastly, students visit a series of dynamic models which depict different types of plate convergence, namely, oceanic-oceanic convergence, oceanic-continental convergence, and continental-continental convergence. Again, students' understanding is scaffolded via a text which direts their processing of the causal and dynamic information in each model as it "runs". (See Appendix A, Activity 5, Steps11 for these tasks).

To view "What's on your Plate?"—you can either start an account for yourself, or go to an account that has already been set up (but it may have others' work in it that cannot be changed) on the computer provided. To get your own account for this unit, go to the W.I.S.E. new student registration page which is bookmarked http://wise.berkeley.edu/pages/newStudent.php Fill in with your: First name, Last name, for PERIOD, put 10, enter a password of your choice, for your student registration code, type SZP87G. Click on "go to the student portal."Or to go to an account that is already set up, go to wise.berkeley.edu, click on Member entrance, and for login enter "AnonyM1" and "try" as your password.Click on "Plate Tectonics: What's on Your Plate?".

Research Approach & Question. In order to address our research question, we used a design study approach (Linn, 1999; Brown, 1992; diSessa, 1991). Design studies are used to investigate the impact of decisions about curricular materials with the express goal of redesigning them in accordance with the findings obtained (Linn, 1999)[3]. We take the design study approach since this is the approach which works best with classrooms in which WISE is fully integrated into the science instruction. Our question was: in what ways does model-building, learning with dynamic runnable visual models in WISE, and the process of critiquing peer's models promote a deeper understanding of the nature of science as a dynamic process?

METHOD

Participants. Approximately 1110 students participated in the Spring 2001 implementation of "What's on your Plate?" These were drawn from 34 middle and high school classrooms across California and Massachusetts. From this large data set, data from 15 middle school classrooms was chosen as the topic of discussion for this paper; this represents data from three different teachers (1 in California and 2 in Massachusetts) each with five Science classes. The total number of students upon which this subset is based is approximately 360.

Procedure.
Pre-test and Post-Test. Students were given pencil and paper survey to assess both their content knowledge of the plate tectonics (not discussed here), and their understanding of the nature of models both before and after the unit; the same test was given before and after. The nature of models part of the test was adapted from Gobert & Discenna (1997), and includes the following questions:

- ➔ How would you describe what a model (in science) is to someone who didn't know this term. Give two examples of models.
- ➔ What are models in science used for?
- ➔ How close does a model have to be to the real thing?
- ➔ What is important to include in a scientific model?
- ➔ Can scientists have more than one model for the same thing? Explain your answer.
- ➔ Are there circumstances that would require a model to be changed? If yes, what are they? If no, why not?

The description of how the models survey was scored can be found in Appendix B.

RESULTS

The students from one class on the West coast were partnered with the students from two classes on the East coast because of the differences in class sizes. Five such sets or "virtual classrooms" (referred to as WISE periods) were created in WISE.

---

[3] Findings from the 2001 was used to revise the curriculum unit and the new unit was implemented again in Spring 2002.

Data analysis. The data analysis is described in three parts. The first part describes the increases made in students' understanding of the nature of models as measured by pre-post gains. The second part describes examples of pre-post gain in specific students. The third part describes students' critique of their peers' models, and the resulting model revision as an example of how their understanding of models was used to critique other students.

<u>Part. 1</u>: Analysis of Variance of WISE periods 1-5. Analysis of variance was used on the total pre- and post-score on the models survey and computed for each WISE period (1-5). Again, since this is a design study, we are not comparing these to a "control" group, so the purpose of the analyis of variance is to get a general sense of whether the students' undersanding of the nature of models (as measured by the survey) changed after the unit; also we are looking for different patterns of results across the three teachers (although that is not the focus of the present analysis).

In all five WISE periods, students scored higher on the models survey after the unit then they did before the unit. In each WISE period, collapsing over teacher, the effect is significant. See Appendices C1.1, 2.1,3.1,4.1,and 5.1 for the relevant anova table, tables of means and standard deviations, and figures.

<u>Part 2</u>. In the next section, examples of students' responses on the pre- and post-test data are given to show how students' understanding of models changed as a result of the model-based unit, "What's on your plate?". In the examples given, the scoring is in parentheses, e.g. (2) and the italicized parts show why it was coded as such.

Question 1: How would you describe what a model (in science) is to someone who didn't know this term?

<u>Seth W.</u>
Pre: Cardboard box, slinky (draws pictures of each) (1)
Post: A model visually shows something. One model could stand still, another could move. (draws pictures- 2d earth with plain, plateau, lake and a wave over land) the wave moves (2)

<u>Kevin F.</u>
Pre: no response (0)
Post: I would describe *a model as a symbol for something in the real world or almost a visual dictionary for a process in science.* A model in science could show making of volcanoes, like what we did in the WISE project or even the formation of a log into petrified wood. (3)

<u>Rebecca P.</u>
Pre: When companies make cars they don't just make the car, *first they make a mini one,* a model car, a model airplane, model volcano. (2)
Post: A model is something that helps to show or *explain*. (3)

Question 2: What are models in science used for?

Madeline

Pre: They are used to *explain information*. (2 ambiguous use of explain)
Post: Showing people *how and why things happen*. (3)

<u>Kevin F.</u>

Pre: To show something *that happens for science in a smaller area*. (2 ambiguous use of happens)
Post: Models in science are used for *showing a process that happens in real life that is hard to make a copy of,* such as formation of volcanoes. (3)

Question 3: How close does a model have to be to the real thing?

Christian G

Pre: It *has to be pretty close* but it depends. (1)
Post: It *has to be close enough that you can take information from it*. (2)

<u>Jenna B.</u>
Pre: A model has to *almost be exact to be the real thing*. (1)
Post: A model has to be pretty close to the real thing if *it's going to show something happening*. (2)

<u>Molly B.</u>
Pre: It could be anything that has *something to do with your topic. If you had to do a model of a cat, you could do a poster with pictures.* (0)
Post: A model just has to show what it is or *how it works*, so it really depends on the project. (3)

Henry B.
Pre: A model doesn't have to be too close to the real *thing as long as it could be recognized as the real thing.* (2)
Post: It only has to be as close to the real thing *so that people could understand the real thing* from the model. (3)

<u>Allison C.</u>
Pre: A model has to be, maybe *not exact but very accurate to the real thing*. (2)
Post: A model doesn't have to be exact but it has to be fairly accurate and *explain in detail how the real thing works.* (3)

Question 4: What is important to include in a scientific model?

<u>Jamyn G.</u>
Pre: All the different parts of the model. (1)
Post: An important thing to remember to include in a scientific model is a key, labels, or some kind of information that would help us to better understand it. (2)

<u>Jocelyn C.</u>
Pre: *So you do not make a mistake on the real thing*. (2)
Post: *The details and movement to prove things*. (3)

<u>Kaitlin P.</u>
Pre: *A scale of the size* if it has changed. (2)
Post: *All of the evidence to how you came up with the model* and an explanation of it. (3)

Question 5: Can scientists have more than one model for the same thing?

<u>Kate W.</u>
Pre: *No,* because for each thing you *could include all the information in one model*. (0)
Post: Yes, because *there can be more than 1 different way to solve the problem*. (3)

<u>Nick L.</u>
Pre: no response (0)
Post: Yes, they can because *not all the scientists are going to have the same evidence and explanation on something.* (3)

<u>Jose G.</u>

Pre: Scientists can have more than one model *to explain another part of something*. (2)
Post: Scientist can have more than one model because they might need *to explain one thing that is part of another thing to show how it works as a system.* (3)

Adam J.
Pre: Yes, it may be *a model of something in the model*. (2)
Post: Yes they can. *If they disagree with one model, they go onto the next and test it.* All the models should be tested to see if they're true. (3)

Nick F.
Pre: Yes you make *different ones for different things*. (2)
Post: yes, they can have *different models emphasizing different things they are trying to prove*. (3)

Question 6: Are there any circumstances that would require a model to be changed?

Chrissy D.
Pre: Yes, if it was dangerous. (1)
Post: Yes there are always because sometimes the information changes. (2) – doesn't say whether the object changes or there is new information)

Mark C.
Pre: ?? (0)
Post: Yes, *if you are trying to figure out what it would look like in a few hundred years*. (3)

Jocelyn C.
Pre: Yes, if it has *some glitch* that is bad. (1)
Post: If something is built wrong they have to change it *or add variables.* (3)

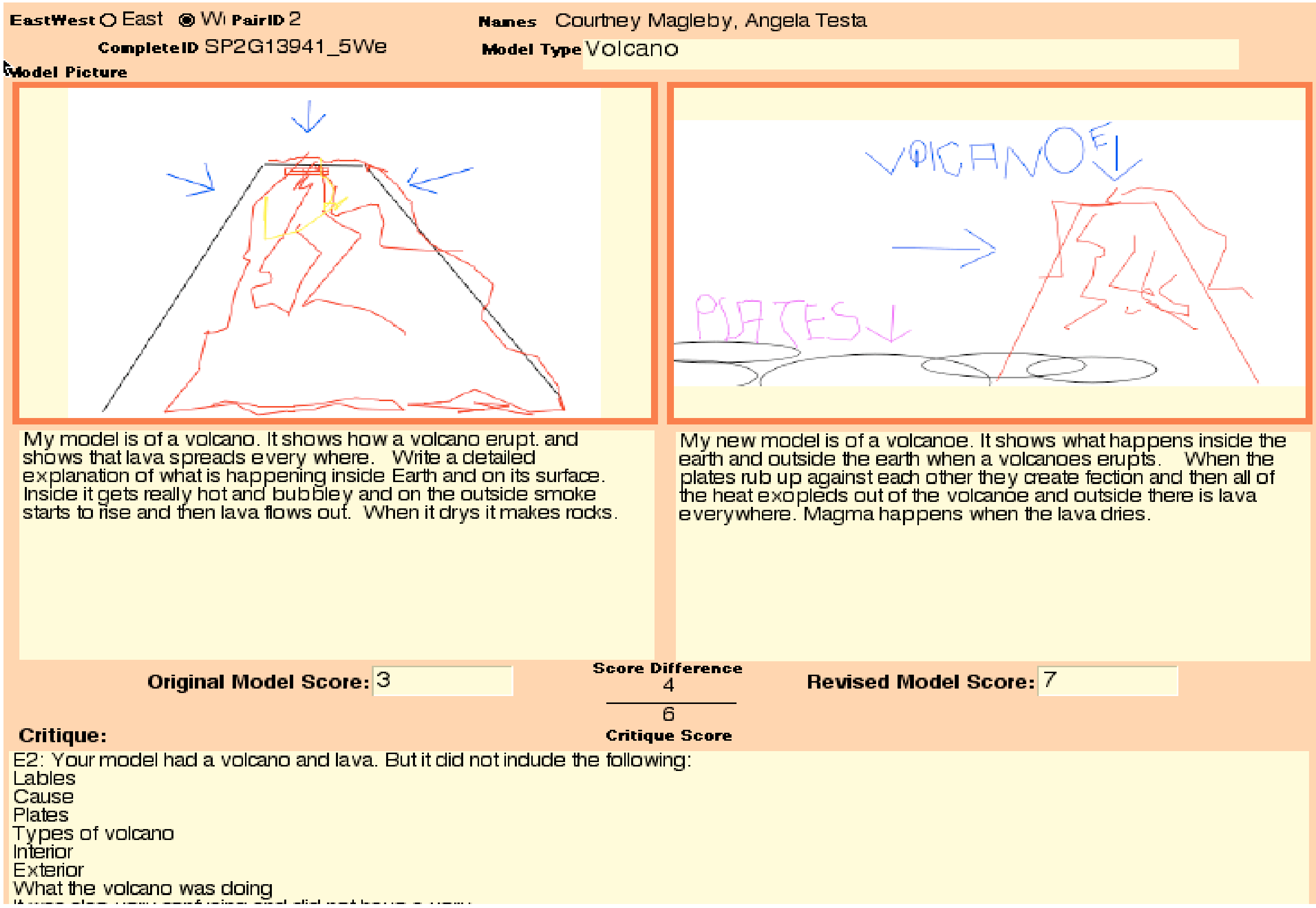
Peter L.
Pre: You'd *also have to change it on the real thing*. (2)
Post: Yes, if they *found out something new* about the object. (3)

Alex M.
Pre: Yes, because if something happens and *the model shows the way it was before it changed then it would be wrong.* (2)
Post: Yes if *more research proved the thing wrong*. (3)

Part 3.

In this section, data is shown in order to illustrate how students' used their knowledge of models and what constitutes an effective model from a communication viewpoint to critique their peers' models. In the following examples, the model on the left is the students' original model and explanation. On the bottom under "Critique" is their learning partners' evaluation (these are their partners from the opposite coast). On the right is students' revised model and their revised explanation.

Examples of Models, Explanations, Learning Partners' Critiques and Revisions for Volcanic Eruption & Mountain Building.


EastWest ○ East ◉ Wı PairID 2
CompleteID SP2G13941_5We
Names Courtney Magleby, Angela Testa
Model Type Volcano
Model Picture

My model is of a volcano. It shows how a volcano erupt. and shows that lava spreads every where. Write a detailed explanation of what is happening inside Earth and on its surface. Inside it gets really hot and bubbley and on the outside smoke starts to rise and then lava flows out. When it drys it makes rocks.

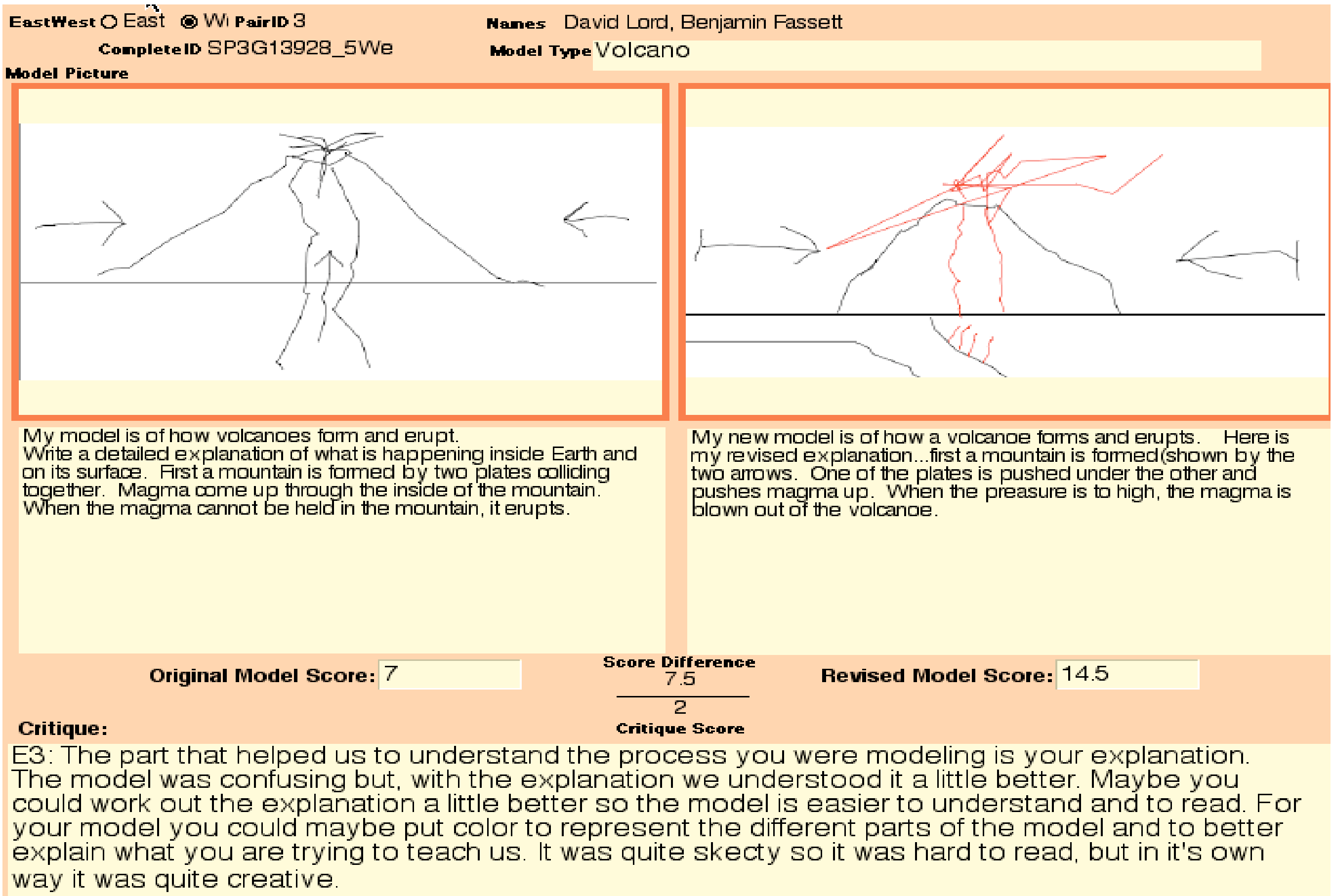
My new model is of a volcanoe. It shows what happens inside the earth and outside the earth when a volcanoes erupts. When the plates rub up against each other they create fection and then all of the heat exopleds out of the volcanoe and outside there is lava everywhere. Magma happens when the lava dries.

Original Model Score: 3
Score Difference 4
6
Critique Score
Revised Model Score: 7

Critique:
E2: Your model had a volcano and lava. But it did not include the following:
Lables
Cause
Plates
Types of volcano
Interior
Exterior
What the volcano was doing

In this example, the students drew a model of volcanic eruption which includes only the crustal layer of the earth; that is, the inside layers of the earth are not depicted, nor are there any internal causal mechanisms responsible for volcanic eruption included in either the model or explanation. This type a model is called a "local" model and is consistent with previous research in this domain which showed that many students of this age group have models of plate tectonic phenomena which only include processes on the surface of the earth, i.e., they do not include the processes and mechanisms inside the earth (Gobert, 2000). The correct conceptions that are represented in the model and/or explanation are: hot magma, movement of magma beyond the volcanic cone, and magma forming new rock. The learning partners' critique is very detailed in that it suggests that the students' model needs "labels, cause, plates, types of volcano, interior, exterior, and what the volcano was doing". The students' revised model includes some the learning partners' suggestions. The revised model, includes labels and the students have elaborated on one type of volcano as requested by their learning partners. More specifically, their explanation it appears the students were trying to depict/describe volcanism due to oceanic-continental plate convergence [4].. The students have also included plate movement and plate friction as causal mechanisms responsible for volcanic eruption. Although the revised model only includes a few additional causal mechanisms from the original, it is a significant advance over their original model.

4


EastWest ○ East ◉ Wi PairID 3 Names David Lord, Benjamin Fassett

CompleteID SP3G13928_5We Model Type Volcano

Model Picture

My model is of how volcanoes form and erupt.
Write a detailed explanation of what is happening inside Earth and on its surface. First a mountain is formed by two plates colliding together. Magma come up through the inside of the mountain. When the magma cannot be held in the mountain, it erupts.

My new model is of how a volcanoe forms and erupts. Here is my revised explanation...first a mountain is formed(shown by the two arrows. One of the plates is pushed under the other and pushes magma up. When the preasure is to high, the magma is blown out of the volcanoe.

Original Model Score: 7 Score Difference 7.5 Revised Model Score: 14.5

2

Critique Score

Critique:

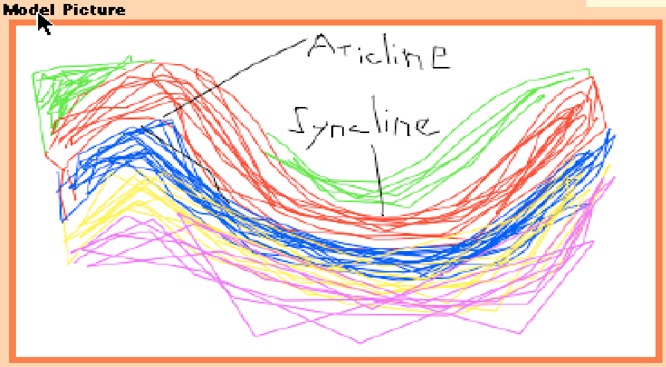
E3: The part that helped us to understand the process you were modeling is your explanation. The model was confusing but, with the explanation we understood it a little better. Maybe you could work out the explanation a little better so the model is easier to understand and to read. For your model you could maybe put color to represent the different parts of the model and to better explain what you are trying to teach us. It was quite skecty so it was hard to read, but in it's own way it was quite creative.

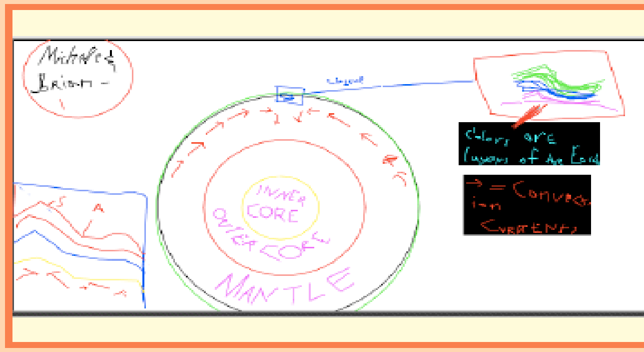
In this example the students' model represents a misconception, i.e., that a mountain is formed and fills up with lava and when it fills up, it erupts. Unfortunately, the learning partners' critique did not include much information upon which a revision could be based; this is possibly due to them not knowing what to do in the case of an "incorrect" model. In the revised model and explanation (which we assume is based on the content of the unit rather than the learning partners' critique), the students have added magma movement as a causal mechanism in how mountains are formed and have also included the concept of pressure as building up within the volcano. It is important to note that although their reasoning here is not entirely correct, intuitive conceptions such as pressure are rich, effective pieces of knowledge that can be effectively built upon (Clement, Brown, & Zietsman, 1989) and are usable anchors for developing understanding of convection (Gobert & Clement,1994). As such the revised model represents gain in understanding.

EastWest ◉ East ○ W **PairID** 13 **Names** Michelle Bilodeau, Brian Guay

CompleteID SP13G13805_5Ea **Model Type** Mountain Building

Model Picture





My model is of the creation of a fold mountain; the Appalachians were made this way. The lowest part of the green surface is called the syncline. The syncline is a downward fold in the rock. The top of the green surface is the anticline; the upward fold in the rock. Folds vary in size, some more than others. Sometimes you need a magnifying glass to see a fold clearly, while others are as big as mountains. Our fold mountain has 2 synclines and one anticline. The Appalachian mountains are made up of lots of anticlines and synclines; maybe thousands. There are too many to count.

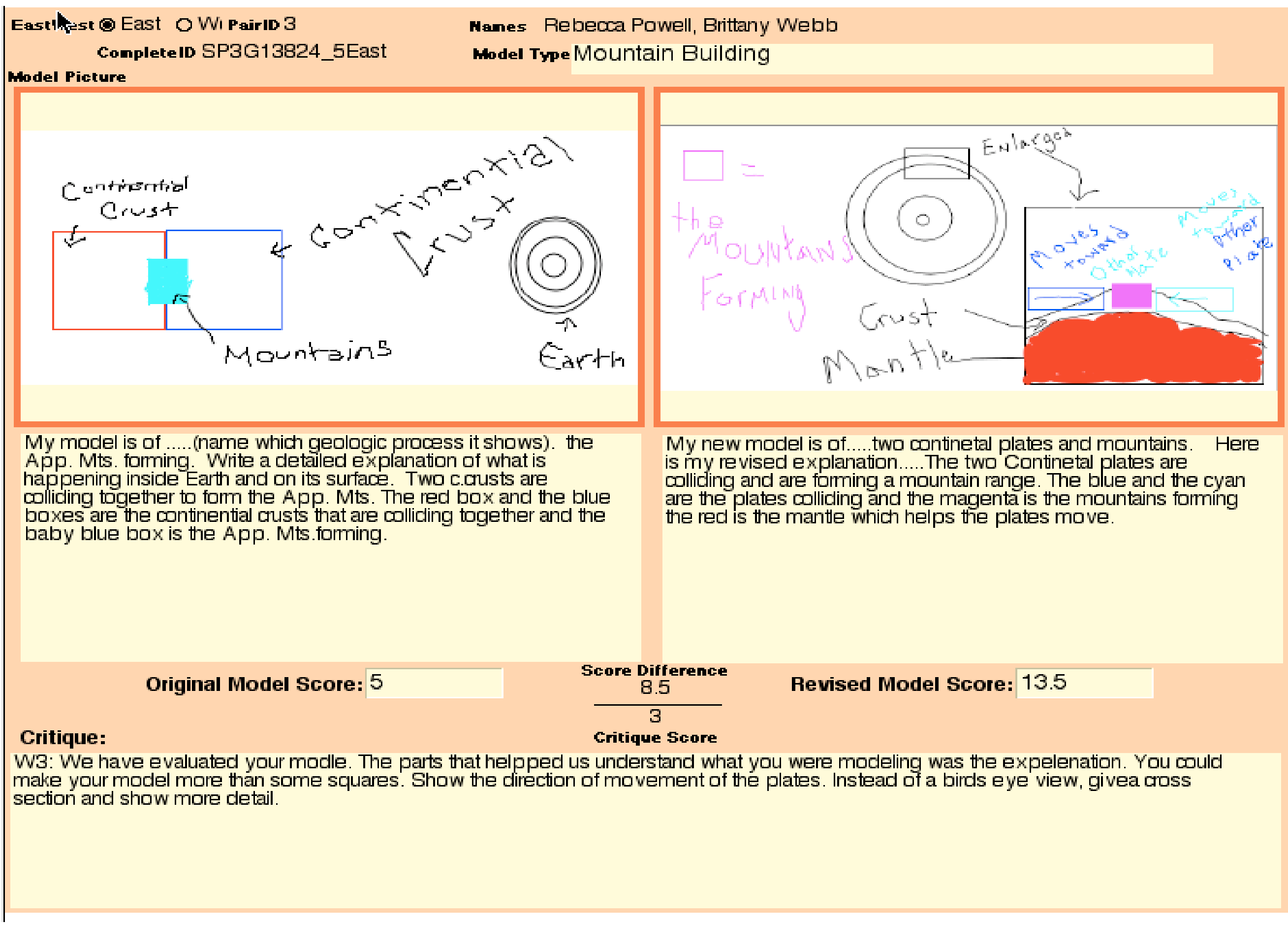
There are also three other types of boundaies; divergent, where new crust is formed; collision boundaries where two land masses collide; and transform boundaries where two land masses slide against each other. Geological features are subduction. Subduction swallows up the ground so Earth doesn't grow. At a depth of 190-430 meters the rocks begin to melt. Some of the melted rock, now lava, goes up to the surface of ocean and creates volanos. Most of it becomes a piece of the mantle, to reappear on the surface in a different boundary.

Original Model Score: 2 **Score Difference** 10 / 1 **Critique Score** **Revised Model Score:** 12

Critique:

W13: We have evaluated your model.The parts that helped us to understand the process you were modeling were the labels that you had("anticline and syncline").We will also make the following suggestions that will help us better to understand your model.Label the colored part of you model.Put all the important labels on your model(enough for a person who hasn't learned this before to get the idea).

In this original model above (left), the students had focussed on the crustal layer of the earth and had not included what happens inside the earth when mountains are formed; that is, there is no structural information or causal information about the inside of the earth. Again, this is a "local" model of plate tectonic phenomena (Gobert, 2000) because it does not include any processes or mechanisms inside the earth. In the critique which was done by their West coast partners, the learning partners requested that they label their model. The revised model includes labels (as suggested); it is also a much more detailed model, suggesting that the students learned a great deal from the content in the "What's on your plate?" curriculum. Their new model includes the crustal layer as a "cut away" from the cross section view; it also includes convection as a causal mechanism in mountain building (in the original model there were no causal mechanisms included). The inclusion of convection as a causal mechanism in their revised model represents a significant advance from their earlier model (Gobert, 2000).


EastWest ◉ East ○ West PairID 3 Names Rebecca Powell, Brittany Webb

CompleteID SP3G13824_5East Model Type Mountain Building

Model Picture

My model is of .....(name which geologic process it shows). the App. Mts. forming. Write a detailed explanation of what is happening inside Earth and on its surface. Two c.crusts are colliding together to form the App. Mts. The red box and the blue boxes are the continental crusts that are colliding together and the baby blue box is the App. Mts.forming.

My new model is of.....two contineta1 plates and mountains. Here is my revised explanation.....The two Contineta1 plates are colliding and are forming a mountain range. The blue and the cyan are the plates colliding and the magenta is the mountains forming the red is the mantle which helps the plates move.

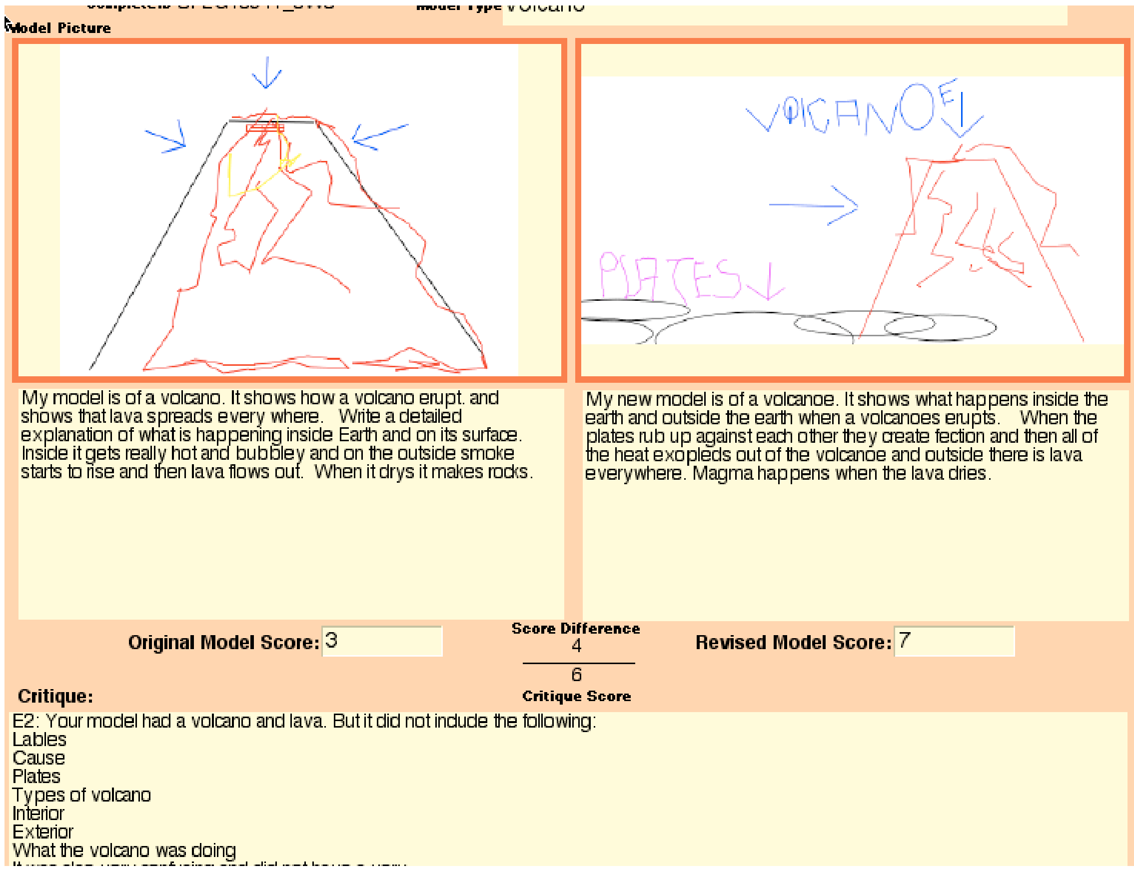
Original Model Score: 5 Score Difference 8.5 Revised Model Score: 13.5

3 Critique Score

Critique:

W3: We have evaluated your modle. The parts that helpped us understand what you were modeling was the expelenation. You could make your model more than some squares. Show the direction of movement of the plates. Instead of a birds eye view, givea cross section and show more detail.

In this example, the students' original model has two views: a cross section view, and a crustal layer view. Their model and explanation include no causal mechanisms in terms of what happens inside the earth when mountains are formed; thus, it is a local model (Gobert, 2000). In the critique from their learning partners', it was suggested that the students include the direction of movement of the plates. This is a high level comment in that it reflects that the reviewers knew that this information was important to the causality of the system being depicted. The



critique also includes comments related to the model as a communication tool, i.e., they suggested that the students include a cross section view rather than a bird's eye view which is good comment regarding the model as a communication tool. The revised model includes the earth in cross section form with a cut away that includes information about the plates moving toward each other. Although not a significant advance from the point of view of including more detailed causal information, the revised model is a better model from a communication standpoint, as was requested by their learning partners.

Discussion

The purpose of the study was to effectively implement the "What's on our plate?" curriculum into multiple sixth grade classrooms and investigate whether the curriculum, a rich, model-based inquiry unit, could influence students' understanding of the nature of models, and to investigate whether students would be able to use what they learned about models in order to critique others' models.

Data analysis from the study thus suggests that students were able to achieve a deeper understanding of the nature of models, as evidenced by significantly higher scores on the post-test. Furthermore, we assume that this was due to their experiences with the unit. Further data analysis is necessary in order to characterize students' reasoning with models as a possible index of how their understanding of models is used in situ. This is particularly important since there is currently debate as to whether students' epistemologies can be measured using a pencil and paper task (Hammer, personal communication, 2001). Additional analysis of this data (which is stored on the WISE server) will provide insight into this, in particular if those who have a very sophisticated understanding of models are also able to use this knowledge to reason with models, do model critiquing, etc.

Summary

This research utilized a state-of the art science learning environment, WISE, to promote deep learning of subject-matter material in plate tectonics (not discussed here); promote the development of students' epistemological knowledge of science as a dynamic, inquiry-driven process, and the nature of scientific models as representations of scientific phenomena used for descriptive and predictive purposes. Preliminary data analysis suggests that students' did achieve a deeper understanding of the nature of models through their interactions with the unit. Furthermore, these preliminary data analysis suggests that they were able to

This approach to science education is compatible with newly recognized standards that the use of modeling tasks and tasks that emphasize the nature of science are important components for learning in science (Linn & Muilenberg, 1996; Hewson, 1999) that can significantly impact lifelong learning and scientific literacy (Linn & Muilenberg, 1996).

REFERENCES

Bencloski, J. W., & Heyl, R. J. (1985). Teaching plate tectonics with the aid of a model of sea-floor dynamics. *Journal of Geological Education,* 33, 274-276.

Brown, A. L. (1992). Design experiments: theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences,* 2(2), 141-178.

Carey, S., and Smith, C. (1995). *On understanding the nature of scientific knowledge*. In D. Perkins, J. Schwartz, M. Maxwell West, and M. Stone Wiske (Eds.), Software goes to school, Oxford, UK: Oxford University Press.

Collins, A., Brown, J.S., & Hollum, A. (1991). Cognitive Apprenticeship: Making thinking visible. *American Educator*, 6(11), 38-46.

diSessa, A. A. (1991). Local sciences: Viewing the design of human-computer systems as cognitive science. In J. M. Carroll (Ed.), *Designing Interaction: Psychology at the Human-Computer Interface*, (pp. 162-202). Cambridge, England: Cambridge University Press.

Feather, R., Snyder, S., & Hesser, D. (1995). *Earth Science*. Westerville, Ohio: Glencoe/McGraw-Hill.

Gilbert, S. (1991). Model building and a definition of science. *Journal of Research in Science Teaching,* 28(1), 73-79.

Gobert, J. (1997b). *Summarizing, Explaining, and Diagramming: The Differential Effects on Text-Base Representations and Mental Models.* Presented at the Nineteenth Annual Meeting of the Cognitive Science Society. Stanford University, August 7-10. Palo Alto, CA.

Gobert, J. & Clement, J. (1999). Effects of student-generated diagrams versus student-generated summaries on conceptual understanding of causal and dynamic knowledge in plate tectonics. *Journal of Research in Science Teaching,* 36(1), 39-53.

Gobert, J. & Discenna, J. (1997). *The Relationship between Students' Epistemologies and Model-Based Reasoning.* Kalamazoo, MI: Western Michigan University, Department of Science Studies. (ERIC Document Reproduction Service No. ED409164).

Gobert, J. (2000). A typology of models for plate tectonics: Inferential power and barriers to understanding. *International Journal of Science Education, 22(9),* 937-977.

Gobert, J., Coleman, E., Scardamalia, M., and Bereiter, C. (1993). *Restructuring the classroom: Implementing knowledge-building via CSILE*. Presented at the Annual Meeting of the American Educational Research Association, Atlanta, GA.

Grosslight, L., Unger, C., Jay, E., and Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. *Journal of Research in Science Teaching*, 28(9), 799-822.

Hammer, D. (July, 2001). Informal discussion at CILT Epistemology Workshop, Concord, MA, The Concord Consortium.

Hewson, P. (1999). *Science. State of the Art session for Division C*. Presented at the Annual Meeting of the American Educational Research Association. April 19-23, Montreal, Canada.
Inhelder, B. & Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence*. New York: Basic Books.
International Association for the Evaluation of Educational Achievements [IAEEA], (1988). *Science achievement in seventeen countries: A preliminary report*. Elmsford, NY, Pergamon Press, 125.
Jackson, S., Stratford, S., Krajcik, J., & Soloway, E. (1994). Making dynamic modeling accessible to pre-college science students. *Interactive Learning Environments*, 4(3), 233-257.
Le Grand, H. E. (1991). *Drifting continents and shifting theories*. Cambridge, UK: Cambridge University Press.
Linn, M. C. (1998b). *Supporting teachers and encouraging lifelong learning: A web-based integrated science environment (WISE)*. Proposal funded by the National Science Foundation.
Linn, M. C. (1999). Designing the knowledge integration environment: The partnership inquiry process. Created for *International Journal of Science Education*.
Linn, M. C., & Hsi, S. (2000). *Computers, Teachers, Peers: Science Learning Partners*. Hillsdale, NJ: Erlbaum.
Linn, M. C., & Muilenberg, L. (1996). Creating lifelong science learners: What models form a firm foundation? *Educational Researcher,* 25 (5), 18-24.
Linn, M. C., diSessa, A., Pea, R. D., & Songer, N. B. (1994). Can research on science learning and instruction inform standards for science education? *Journal of Science Education and Technology,* 3(1), 7-15.
Penner, D. E., Giles, N. D., Lehrer, R., Schauble, L. (1997). Building functional models: designing an elbow. *Journal of Research in Science Teaching,* 34(2), 125-143.
Perkins, D. (1986). *Knowledge as design*. Hillsdale, NJ: Erlbaum.
Plummer, C. & McGeary, D. (1996). *Physical Geology*. Wm. C. Brown Publishers.
Raghavan, K. & Glaser, R. (1995). Model-based analysis and reasoning in science: The MARS curriculum. *Science Education,* 79*,* 37-61.
Sabelli, N. (1994). On using technology for understanding science. *Interactive Learning Environments,* 4(3), 195-198.
Schwarz, C. & White, B. (1999). *What do severnth grade students understand about scientific modeling from a model-oriented physics curriculum?* Presented at the National Association for Research in Science Teaching, March 28 - 31, Boston, MA.
Smith, C., Maclin, D., Houghton, C., & Hennessy, M. G. (1999). *Can 6th-grade students develop a coherent constructivist epistemology of science: A comparative study*. Presented at the National Association for Research in Science Teaching, March 28 - 31, Boston, MA.
White, B. & Frederiksen, J. (1990). Causal model progressions as a foundation for intelligent learning environments. *Artificial Intelligence*, 24, 99-157.

APPENDIX A

The Unit--*What's on Your Plate?*

❖{Before WISE unit: Content and Nature of Models Pre-test}

❖ACTIVITY 1: What's on your plate?
•Step 1**: Introduction to this project.**
•Step 2**: What do you know? Students describe what they know about the geology of the region nearest where they live (East or West coast).**
•Step 3**: Draw your models. Students draw a model of an earthquake or volcano (West coast only) or mountain building (East Coast only)**
•Step 4: **Explain your model. Students write an explanation of their models.**

❖ACTIVITY 2: On-line Field Trip
•Step 1**: Introduction to the online field trip.**
•Step 2**: Explore Evidence: Earthquakes in the United States: Students view a map showing "real-time" data of recent earthquakes in North America.**
http://earthquake.usgs.gov/activity/present.html
•Step 3**: Write a summary note: Students record what they have learned about the occurrence of earthquakes in the region near where they live.**
•Step 4**: Explore Evidence: Active Volcanoes in the United States: Students look at "real time" data of volcanic activity in North America.**
http://volcano.und.nodak.edu/vwdocs/volc_images/north_america/north_america.html
•Step 5**: Write a summary note: Students record what they have learned about volcanoes in the region near where they live.**
•Step 6**: Explore Evidence: Mountain Ranges in the US: Students look at elevation, contours, and relief maps to determine the location of Mountains in North America.** **http://www.nationalatlas.gov/relief.html**
•Step 7**: Write a summary note Students record information about the mountain ranges near where they live.**

❖ACTIVITY 3: Share Your Journal
•Step 1**: Introduction**
•Step 2**: Show your journal. Students select journal responses and make them available to their learning partners on the opposite coast.**
•Step 3**: View Learning Partner's Journal**
•Step 4**: Write a reflection note about the differences between E and W coasts by comparing their journal responses to their learning partners journal responses.**

❖ACTIVITY 4: Earth's Plates
•Step 1**: Plate Boundaries. Students view a map illustrating Earth's plate boundaries. http://geology.er.usgs.gov/eastern/plates.html**
•Step 2**: Note about plates near you. Students relate location about plate boundaries with evidence they discovered in activity two.**

•Step 3**: Reflection Note: Write one (or two) question(s) you have about plate boundaries or plate movement that will help you better understand why the geologic processes on the West and East coasts are different. Students revisit these questions in a Discussion Forum later in the unit.**

❖ACTIVITY 5: Plate Tectonics

•Step 1**: Introduction to different types of plate boundaries**

•Step 2**: Gathering Evidence: Convergent Boundaries In this step students explore the geologic features associated with convergent plate boundaries. Students view a dynamic model.**

•**http://www.pbs.org/wgbh/aso/tryi/tectonics/**

•Step 3**: Reflection note: Students describe geologic features that are typical of convergent boundaries.**

•Step 4**: Gathering Evidence: Divergent Boundaries: Students return to the same web site as above and explore geologic features associated with divergent boundaries.**

•**http://www.pbs.org/wgbh/aso/tryi/tectonics/**

•Step 5**: Reflection note: Students record their observations.**

•Step 6**: Gathering Evidence: Transform Boundaries Students once again return to the dynamic model above and explore transform boundaries.**

•**http://www.pbs.org/wgbh/aso/tryi/tectonics/**

•Step 7**: Reflection note: Students describe geologic features associated plates sliding past each other.**

•Step 8**: Introduction to The Mantle: Students read about convection in the mantle**

•Step 9**: The Mantle. Students observe a cross section of Earth and a dynamic model illustrating convection in the mantle. http://learnertools.com/concord/layers/5-1/layers.html**

•Step 10**: Reflection Note: Students explain how processes inside Earth relate to plate movement.**

•Step 11**: A Closer Look: Students look at several dynamic models that relate mantle circulation to geologic features on Earth's surface.**

•**http://learnertools.com/concord/oceanic-oceanic/5-1/oceanic-oceanic.html**

•**http://learnertools.com/concord/oceanic-continental/5-1/oceanic-continental.html**

•**http://learnertools.com/concord/continental-continental/5-1/continental-continental.html**

❖ACTIVITY 6: Models in Science

Step 1**: Introduction to "What is a Scientific Model?"**

Step 2**: Open Me First (a way to make sure that the drawing tool works.)**

- Step 3**: Show Your Model Students make their models (of how earthquakes happen, mountain form or volcanoes form) and their descriptions available for their learning partners.**
- Step 4**: Examine learning partners' model:**
- Step 5**: Evaluate your learning partners' model. Students use an assessment form to evaluate their learning partners' models and descriptions. Prompts include:**

- **Are the most important features in terms of what causes this geologic process depicted in this model?**
- **Would this model be useful to teach someone who had never studied this geologic process before?**
- **What important features are included in this model? Explain why you gave the model this rating.**
- **What do you think should be added to this model in order to make it better for someone who had never studied this geologic process before?**

- Step 6**: Share Your Evaluation: Students summarize their evaluations and make these summaries available for their learning partners.**

❖ACTIVITY 7: Model Revision

- Step 1**: Do it: Students' revise model based on learning partners critique and Activities 2-5.**
- Step 2**: Explain your new model. Students write an explanation of the new model.**
- Step 3**: Reflection Note on new model. Prompts include:**

  - **I changed my original model of.... because it did not explain or include....".**
  - **"My model now includes or helps explain…"**
  - **"My model is now more useful for someone to learn from because it now includes…."**
  - **"I revised this on the basis of my learning partners' critique in the following ways….**
  - **"I revised this on the basis of the activities in these WISE units….. "**

ACTIVITY 8: What have we learned?

- Step 1**: Introduction to on-line forums.**
- Step 2**: On-line forum begins: Students revisit the questions they wrote in Activity one and discuss what they have learned and their thoughts and ideas in each category (Earthquakes, Volcanoes, Mountains, & Plate Characteristics).**
- Step 3**: How can that be? Based on what students have learned, students explain the following:**

  - **How can there be mountains on the East Coast when there is no active plate boundary there?**
  - **What will the coast of California look like in the future?**

{POST-TEST for content gains and modeling knowledge}

APPENDIX B—Model scoring and examples

Question 1: What is a model?

code	Description	Examples from "H's Class	Researchers' Examples/Elaboration:
0.	No response or not interpretable.	No response: S5, S7, S9, S11	A fashion model.
1.	Student gives an example of a model with no explanation of how it is 'model-like'.	S13: A seismograph. A thermometer. S4: A visual aide. A type of occurrence. S5b: A model is either a picture with words or a motion object with words. S19: {shows on object jaggedly broken in two pieces titled 'broke' and shows a stick figure with a thought bubble containing a dollar bill also titled 'broak'}	A fashion model, model airplane, a model train. An example of science.
2.	Model understood to be a factual representation.	S1: A diagram of something. A paper mache' volcano. A fudge rock formation. S3: A replica (sometimes smaller, sometimes larger) of a thing. 2 examples: the natural disaster project model and (on ceiling in the science room) the planets on strings in proportion distance to the sun. S8: A model means a usually smaller replica of something. You could create a volcano model by constructing a mountain using baking soda and vinegar to act as magma/lava. You could also create a model on a computer using digital graphics. S10: 1) a smaller form of an object. 2) a less destructive object that represents something else. S11b: 1) a model is something that represents something else. 2) a model is a figure of something. S12: Something to demonstrate. An example. S13b: An instrument used to do something: seismograph used to measure earth quakes or to demonstrate something. S17: A model is a small recreation of an actual object that is man made and usually doesn't do what the real object does. A globe is a model of the earth and a doll is a model of a human. S17b: A model is a replica of an object. Usually a model is many times smaller than the real thing and does not do all the actions the real object	It is smaller than the real thing. Used to show an example. A 3-D picture of mountains. Causal model, map, graph, cross section.

		does. Two examples would be a world globe or a paper mache' volcano.	
2.5	Possible notion that models represent ideas: they help us understand something or show a process. Reference to 'how it works' but it seems that concern is with how the models works, not an idea or phenomena.	S1b: A model is a recreation of an object or event. – a volcanic eruption – a model of a butterfly. S3b: A visual aide to help someone understand something. S4b: Something to illustrate the happenings. Volcano, earthquake. S8b: A 2D or 3D object or picture that allows someone to view a smaller reenactment of something. S10b: A model is the same thing as what your studying but smaller. A model shows what happens. S12b: Something to explain something. S18b: Make a motion model and tell them as they model is going. Make a poster and describe what happens. S66b: How the model works, what causes it.	They show how to dc something. They show what happens. Problems, questions, situations, theories. To help you understand things.
3.	Clear understanding that Models represent Ideas. May show concern with cause – how things work, or why they happen.	S2: A model is something that describes another object like a volcano, to explain how it erupts. An earthquake cake to show what happens during an earthquake. S2b: Models in science are sculptures or drawings to explain/show how something is made/formed. 1) I drew a model of two continental plates colliding 2) you could make a model of a volcano to show how it erupts. S7b: 1) A model is to show you how things work in real life but a lot smaller. 2) A model shows you what happens to stuff. S9b: A theory that explains how something works. S15: A model is a thing that shows how another thing happens or works. If you have 2 models of a volcano for instance, you could have a core with water or some other liquid to represent lava spewing forth from the earth. You could have two pieces of cardboard pushing against each other to show oceanic & continental crust colliding. S15b: A drawing or figure or something similar that shows a process. Like a model of a mountain, and how it formed or a drawing of a volcano erupting.	Models are useful -- as evidence, to show a process, to compare things, to explain things. Models show how something works or provide an explanation.

		S16: A model could be an object(s) that shows how something works. A model could be something shrunken down or recreated to show how something looks. S16b: A model is something that shows how something else works or what happens when something is done.	

Question 2: What are models in science used for?

code	Description	Examples from "H's" class	Researchers' Examples/Elaboration:
0.	No response or response not interpretable.	No response: S84b, S85	
1.	Models are something to look at.	S19: Display S90: Learning what the model is about.	Decoration, something to play with, to show clothes
2.	Models are factual representations of things. They may be hard to see or impossible to see. It may be too dangerous to see them.	S75: Models in science are used for showing people what something is without reading it. S76: They are used to show things that relate to science. S76b: To show something or demonstrate something. S77: To mimic what something looks like but it is shrunken, to help explain to others what something looks like. S77b: Models in science are used to visualize for a person what something looks like. S78: They are used to represent something and demonstrate it. S80: To show something that is shrunk down. S80b: To describe certain things. S84: Showing experiments. [in context of other questions there is not evidence this means more than a representation.] S85b: To show things that you can't see every day. S88b: To show samples.	Replicas to show features you can't see due to scale. Used to measure things, find out facts or answers, collect data, explore, compare (unelaborated).
2.5	Possible understanding that models represent ideas.	S24: To show how the natural disasters happen. S56b: To observe or plan something. S59b: To show geologic processes. S75b: To show what happens with more detail. S79b: To help teach someone about the thing they are learning. S83: Models in science are used to show what happens in a smaller version of something else. (volcano erupts) S83b: Models in science are used to show what the real life structure that the model represents does.	Vague reference to cause: Instructions or recipe how to do something, show what happens, show what something does. To measure or calculate. To help someone learn or understand. To explain a subject or object

		S86: To explain things. S86b: To teach people. S87b:To show what happens after what the model is modeled after. S88: To show the effect of the real thing. S89: To show what is going on under the earth's crust or in a volcano. So you can see what is going on somewhere where you can't see it. S89b: To show something that you can't see or get very close to. Or to explain something that isn't happening right now. Ex: an eclipse or an avalanche. S90b: Explaining a science figure or method to someone.	-no evidence it's not just a description. Show idea (unelaborated).
3.	Models represent ideas, explanations. May show concern with cause – how things work, or why they happen.	*S47b: You could do a model for scientist to test out an idea or thought of some sort. S74: Models are used to – demonstrate how something works – show what the result of something can be on something else – show all of the parts of something. S74b: Models in science are used to explain things, show parts of something, show how something works, or show the cause of something. S78: To show how something science-related works. S79: To show how something works in a smaller version. S81: To show a miniature version of how something happened. S81b: To show how something works. S87: To show how things work (ie volcano)	Used to help people understand, to provide explanations, to make predictions, to provide evidence for something, evaluate or compare data. Used to show how something works, to show how one thing affects another, to tes or do experiments on things or ideas

Question 3: How close must a model be to the real thing?

code	Description	Examples from "H's" class	Researchers' Examples/Elaborati on:
0.	No response or not interpretable	No response: S43, S44, S45, S51	Not too close. Not close. It doesn't matter. About a third of it.
1.	a. Exact or as close as possible, without giving particular requirements for a representation. b. Refers to the materials needed, not what is being represented. c. Has to be the thing assigned.	S10: Close because models are the same, just smaller and made of different substances. S33: It has to be similar but they can replace things with other objects. S38: Pretty close, if it wasn't it wouldn't be a model. S38b: Real close. S44b: It doesn't need to be exactly real. Just use material we kids can use. For a volcano model you only need to make a hand size volcano with dirt or plaster. S47b: A model should be nearly close to the real thing, like if you were doing an earthquake, you wouldn't want to have a volcano exploding in your model, you would want a model of an earthquake. S46b: Close, if it's off it's not technically a model. S50: 50% because of size and length. S50b: Almost exact.	The same except for size. Unelaborated qualities or quantities
2.	Models are factual representations that have requirements -- they need to show what you are modeling. (do not code a 2 for responses that say that if it's a model of a rock you wouldn't draw a river. This is code 1.)	S19b: Enough to tell about it. S37: Should be accurate. Doesn't have to be to scale. Whatever information it shows should be correct. S37b: It should have accurate information. It should be pretty close to the real thing. S41: A model has to be real close to the real thing because - it could mess up the observations, measuring, etc., - if the thing is not real close then may do things incorrect. S45: Well enough so someone can know what it is. S46: Close because the model is pretending to be the real thing, so you need it to be close to the real thing. S48: To give you an idea what it looks like. S48b: Close enough to tell what it is.	It needs the importan features. Same except for scale or proportion. The information in the model needs to be accurate.

2.5	Possible understanding that models represent ideas.	S23: It has to look like a real one and work like a real one. S36b: Close enough that the viewer knows what you're talking about. S40: It doesn't have to be perfect. Just good enough that people understand the concepts of your subject. S40b: Close enough to teach the audience what happens with your model and the important features it has. S41b: Basically near, you don't want it to be some near and not because the function may have a false answer. [too ambiguous to code a 3 for testing] S42: It has to be close to the real thing to show what really happens. S42b: Very close, to show what happens to the fullest extent. S43b: It needs to show what may happen,. It HAS to show what it is so it can really do something, so it makes sense. S49: Smaller, similar, but does the same stuff. S49b: Similar to what it does but not in size or intensity. S51b: A model has to be to scale but based on the theory. S52: A model should be extremely close or close enough to be clear and understandable for a person who doesn't know anything on the subject.	Close enough to be understood, interpreted, answer a question. Helps with explanation, what is needed so people can understand what happens. Concern with what happens, what it does – hints at cause.
3.	Models need to represent the idea that you are modeling. May show concern with cause – how things work, or why they happen.	S36: It has to look somewhat like what it's supposed to be, but it really is to show how something works, so that needs to be really close. S39: Models can be very far away from the real thing. Usually models are made much smaller than the real thing. Models can tell you how something might fail so you don't have to waste money on building it. S39b: It has to be somewhat close so you can get accurate results. S47: A model can be as close as the real thing, but in other cases it doesn't have to be as close. It should be fairly close so that you can actually know how something can occur, (or how it happens.)	Requires causal information, Must replicate the process or function of what it's showing. Requires some testing or proof to be included, or can be tested to provide information/results/proof. Depends on how the scientist envisions the idea being shown.

		S52b: A model should be close enough to the real thing that it is easy to understand and provides a good explanation.	

Question 4: What is important to include in a model?

code	Description	Examples from "H's" class	Researchers' Examples/Elaborati on:
0.	No response or response not interpretable.	No response: S18, S25, S28, S29, S30, S31b, S34, S35 S19: To display.	
1	No evidence of a clear distinction between model and what is being modeled: a. Need everything, all the facts or information. b. Focus on the mechanics, need labels, arrows, titles with no explanation of their purpose in the model.	S18: Everything! S32: Include the same thing in model.	An exact replica. All facts. Information. Arrows, title, headings, labels. Height and weight
2	Focus on factual representation, need to show what you are modeling.	S22: To make it look like the topic it is modeling. S24: The directions, what it is. S25b: Labels, clearness, accuracy. S26: the correct info, the right scale, safe chemicals/ devices. S26b: A scale so that people will know how large it is, colors to help people comprehend and correct info. And directions/instructions and safe chemicals/ instruments. S27: Any important details. S32b: What is the model about. S35b: Almost all that is in the real thing. If it's a mountain, you need a mountain. If there are details, try to include them. If there is a volcano, you obviously can't include the red magma, so you use something that is like it (or as close as you can get).	What you need to so people can tell what you are making. Correct information, useful information, the facts about something, scale.
2.5	Possible understanding that models represent ideas.	S19b: What happens S20: An explanation of the model. S20b: All the factors of a process. S21: Labeling, description, explanation. S22b: An explanation of what is happening and labels.	What people need to learn, understand. Focus on what is happening, not how it happens. Unelaborated

		S24b: Directions, what it is, and make it work. S28b: What makes the thing happen change or move. S29b: Everything it needs to work S30b: labels, an explanation, visual stuff. S31: An explanation. S33: They have to include an explanation and no variables. S33b: Include the basic ideas and important parts.	responses such as explanation, relationships, proof, function, process, evidence-- which could mean they are the purpose or function of the model. Needs to show how the model works – not clear that this refers to how what is being modeled works.
3	Clear understanding that models represent ideas. May show concern with cause – how things work, or why they happen.	S21b: How things work, explanation, and some pictures of movement. S23: How it works. S23b: Labels that say what everything is, and how it works. S27b: Details, how it (the thing the model is of) works. S34b: The movement, the cause.	Focus on how something works or why it happens. What is relevant to an explanation, The steps of a process or function, a prediction or evidence of proof.

Question 5: Can scientists have more than one model for the same thing?

code	Description	Examples from "H's" class	Researchers' Examples/Elaborati on:
0	No, no response, yes—for no reason, or response not interpretable. Seems to misunderstand the question.	No response: S72b S60: Yes, to see if there is any difference. S61: Yes, because they all look different and they all work different. S61b: yes, because if they know a lot about other things. S66: Yes, because it might reperent (sic) some other kind. S75: No Scientists cannot have more than one model of something because there is always one way for everything.	
1	If first one is wrong, to have multiple copies of the same thing, to use different materials or make a different type of model, Or an ambiguous reason that has some hint of a reason.	S54: Yes, to check the answers S54b: . . . so they have backup in case something's wrong. S64: Yes, they can make models different shapes, sizes, color, and make it out of different materials. S64b: Yes, there can be different types of the thing they are creating, there can also be different colors. S71: Yes, there are different ways of making models, and they can turn out different. Ex: a mountain model can be made out of dirt or paper mache'.	It has to be right. As many as they want. To have multiple copies in case one breaks. One for a certain model.
2	A factual representation: can have different aspects views or perspective of the same system – no mention of ideas changing. To show different examples of the same thing.	S55: One could have more information and be more detailed than another, or one could work. S56: They might show different things, like the interior. S56b: Yes, one can be an interior model etc. S58: Yes, one model could be for one part of the real thing another for a different thing and so on and so on. S58b: Yes, one model could be for one part of one thing and another model for another part of one thing. S59: A model does not just have to be on the outside, it can be showing what something looks like on the inside. S60b: Yes, to see if there is something different, and for different examples. S62: Yes, the way a model looks can be roughly	Perspectives could be due to physical positioning. Different kinds/types of models. If the object changes: . Replication without suggestion of testing ideas.

		the same. As long as it gets the idea out. S66b: Yes, sometimes there different types of the model. S69: Yes, because there may be different variations of that thing. S69b: Yes, they can like earthquakes, there are different kinds so you need different models. S70: Yes, because not all models look, function, or work the same, though all might give good representations of the (example) "avalanche". S70b: Yes model can be of the same thing, as long as they all resemble the thing. S72: When you have more than 1 model, one can be for making changes and one can be the original.	
2.5	Possible understanding that models are about ideas, that models change when ideas about things change –e.g. to show new information, or that different models can show different ideas.. To promote understanding. Concern with replicating experiments. (35b)	S11: Yes, they can show two different ways the disaster happens. S53: Yes, because sometimes there are different views or ways of something happening. Ex: there are two ways a volcano can erupt. S55b: Show outside and inside and more things can happen. S59b: They can because one model can show one part about a geologic process and another model can show a different part of the same geologic process. S65: Yes, there could be different steps. [q's 1-4 all mention how something works] S71b: Yes, scientists can have more than one model for one thing because, for example, if a scientist were to show the effects on a town when an earthquake occurs, they could have a before model and an after model.	Use vague causal language but no clear idea of how things work or why things happen. Understanding that models can show a processes but a new model is to show part of a factual representation, not a different idea of why or how the processes occurs.
3	Different models represent different ideas, changes in ideas or different explanations. Show concern with cause – how things work, or why they happen.	S33b: Yes, they can change the variables in the experiment. S53b: Yes, because say you want to show how volcanoes are formed. There's more than one way, so you want to show both. Or, you might want to get two or more opinions on something. S62b: Yes, … one can show why and the other how. Or you could do inside and outside or before and after. S63: Yes, because sometimes you can't show two different things/ideas with one model. S63b: Yes, because sometimes it takes more than one model to display how something works	Different ideas about how it works. To show different thinking, approaches, variables, experiments, mental perspectives. As a result of testing.

		thoroughly. S65b: They can have many. Example: one model on how tornadoes are born, on model on the tornado's damage. S68: Yes, some people might have a different idea about it. S68b: Yes, because different people see things different ways.	

Questions 6: Would you ever change a model? Why?

code	**Description**	**Examples from "H's" class**	**Researchers' Examples/Elaboration:**
0	No, no response or response not interpretable. Yes – unelaborated or for no reason.	No response: S60, S63, S63b, S66, 72b S55: No, they can rebuild it if they need to. They could keep the first one to look back onto.	
1	Ambiguous response with some hint of an idea. If you made a mistake, were wrong, or left something out. If it was dangerous.	S58: Yes, if something in the model was wrong. S60b: Yes, if there mistakes. S61b: Yes, if you don't know anything about it or you have the wrong fact, something has to be changed. S69: Yes, if the model didn't come out right. S72: Yes, if you make a mistake with your model you may have to go in and change it.	There are always mistakes. If you want to
2	Models are factual representations: Change is required when what you are modeling changes. Change is required if the model is not a good enough representation of the facts to be understandable.	S3b: Yes, if the model wasn't complete or didn't explain the happening properly. S53: Yes, if the real thing itself changes. S53b: Yes, because what if you want to correct something? What if the thing that the model represents changes? S54b: If it wasn't clear or there was wrong information on it. S55b: Yes, if something changed about what the model is showing. S56: Yes, if a volcano blew up you would have to blow up the model. S56b: No, because you could just make a new one. If a volcano erupts you could have before and after. S58b: Yes, if a part of the model was wrong or was lacking something or was hard to understand. S59: Yes, because the world is constantly changing, and say if it was a very detailed model of Everest, and something significantly changed on it, the model would have to change to be correct. S59b: yes, if there were tectonic plates they would need to change because every year the plates move (very little) but then a very accurate model would also have to change with the real plates.	Yes, if the object physically changes The product process could change. Yes, such things as earthquakes, tornadoes, floods, etc Models change over time because the data changes.

		S61: yes, because it could get out of date, or become too old. S62b: Yes, if it was missing something or had wrong information or if the actual thing that the model was of changed. S64: Yes, the only circumstances would be if it doesn't work or people don't know what it represents, or if you don't like the looks of it. S64b; Yes, if the person you are showing doesn't know what you're making, or if you're not satisfied with it. S68b: Yes, if whatever it is changes somehow. S69b: Yes, if it was really bad or unrealistic. S70: Yes, the model might not look like or function like the thing it's representing. S70b: Yes, because the model might not look like or function like the real thing. S71: yes, if someone built a model volcano that looked exactly like the real thing but much smaller and in real life that volcano had an eruption and it looked different after, it would be a good thing to change the model to the way the model looked after the eruption. S71b: Yes, if a model was made and then the creator asked for advice on if the model was good enough and they wanted to change it then they should. If a model was, for ex, made of a real volcano and then the volcano exploded and changed then it would probably make sense to change the model.	
2.5	Possible idea that models change when ideas about things change -- to show new information. To show stages or processes To promote understanding.	S54: Yes, if new info is found. S65: Yes, when you're building a model and then a scientist finds out more about the thing you're doing a model of. S65b: Yes, if they find more information. S68: Yes, if they find new info on something that could be shown in the model.	New information -- could mean ideas or just facts and features.
3	Understand that a model must change when ideas change. May show concern with cause – how things work, or why they happen.	S62: Yes, if it is not constructed the right way or does not show how something works correctly. S66b: Yes, it has to show how the thing works. You can't just make one up.	Change to make it a better explanation, more understandable. Change to correctly model cause. As a result of testing the model.

	Concern with fit, if one part changes, you may need to change other parts in order for it to make sense.		Yes, if your ideas or beliefs change. Change must make sense, Changes must fit with the rest of the model Models are dynamic and will change as they function as models.

Appendix C1.1: Model Change Period 1

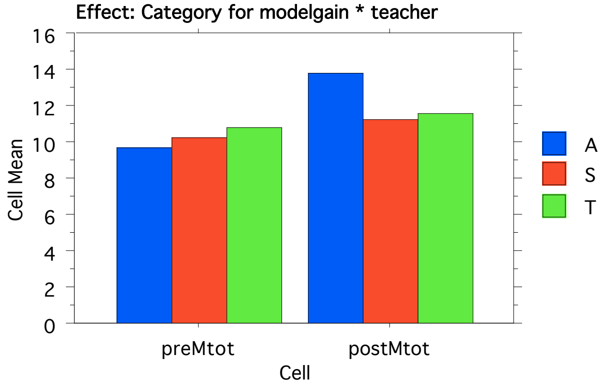
ANOVA Table for modelgain

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
teacher	2	22.442	11.221	.692	.5044	1.384	.157
Subject(Group)	61	988.926	16.212				
Category for modelgain	1	115.697	115.697	16.046	.0002	16.046	.987
Category for modelgain * teacher	2	83.882	41.941	5.817	.0049	11.633	.866
Category for modelgain * Subject(Group)	61	439.837	7.210				

Means Table for modelgain
Effect: Category for modelgain * teacher

	Count	Mean	Std. Dev.	Std. Err.
A, preMtot	29	9.672	4.386	.814
A, postMtot	29	13.793	2.392	.444
S, preMtot	17	10.235	2.835	.687
S, postMtot	17	11.206	2.616	.635
T, preMtot	18	10.833	3.068	.723
T, postMtot	18	11.611	4.418	1.041

Interaction Bar Plot for modelgain
Effect: Category for modelgain * teacher



Fisher's PLSD for modelgain
Effect: teacher
Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value
A, S	1.012	1.571	.2047
A, T	.511	1.543	.5139
S, T	-.502	1.739	.5692

Appendix C 2.1: Model Change Period 2

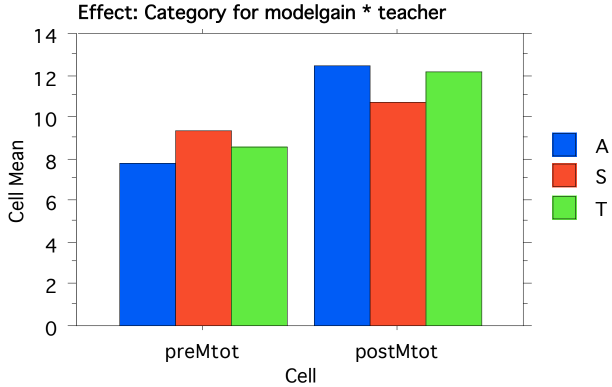
ANOVA Table for modelgain

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
teacher	2	2.335	1.167	.079	.9244	.158	.061
Subject(Group)	59	874.504	14.822				
Category for modelgain	1	311.401	311.401	40.945	<.0001	40.945	1.000
Category for modelgain * teacher	2	56.782	28.391	3.733	.0297	7.466	.659
Category for modelgain * Subject(Group)	59	448.710	7.605				

Means Table for modelgain
Effect: Category for modelgain * teacher

	Count	Mean	Std. Dev.	Std. Err.
A, preMtot	28	7.750	3.693	.698
A, postMtot	28	12.464	2.812	.531
S, preMtot	17	9.294	2.812	.682
S, postMtot	17	10.735	2.927	.710
T, preMtot	17	8.559	4.984	1.209
T, postMtot	17	12.176	2.243	.544

Interaction Bar Plot for modelgain
Effect: Category for modelgain * teacher



Fisher's PLSD for modelgain
Effect: teacher
Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value
A, S	.064	1.632	.9380
A, T	-.289	1.632	.7268
S, T	-.353	1.827	.7028

Appendix C 3.1: Model Change Period 3

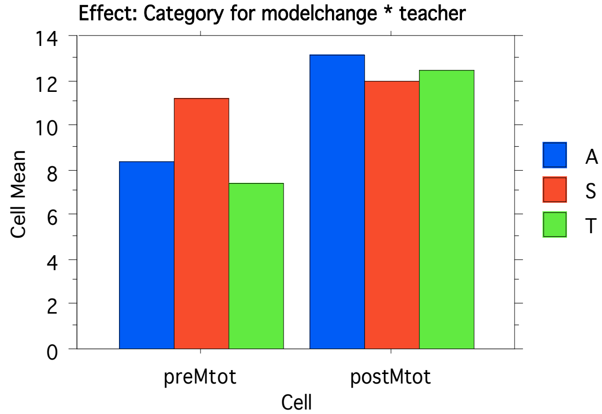
ANOVA Table for modelchange

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
teacher	2	47.195	23.597	1.433	.2464	2.866	.285
Subject(Group)	62	1021.132	16.470				
Category for modelchange	1	366.531	366.531	54.803	<.0001	54.803	1.000
Category for modelchange * teacher	2	106.362	53.181	7.952	.0008	15.903	.958
Category for modelchange * Subject(Group)	62	414.665	6.688				

Means Table for modelchange
Effect: Category for modelchange * teacher

	Count	Mean	Std. Dev.	Std. Err.
A, preMtot	30	8.400	3.885	.709
A, postMtot	30	13.100	2.896	.529
S, preMtot	17	11.206	2.469	.599
S, postMtot	17	11.912	1.314	.319
T, preMtot	18	7.417	5.168	1.218
T, postMtot	18	12.417	3.214	.758

Interaction Bar Plot for modelchange
Effect: Category for modelchange * teacher



Fisher's PLSD for modelchange
Effect: teacher
Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value
A, S	-.809	1.684	.3437
A, T	.833	1.654	.3207
S, T	1.642	1.876	.0857

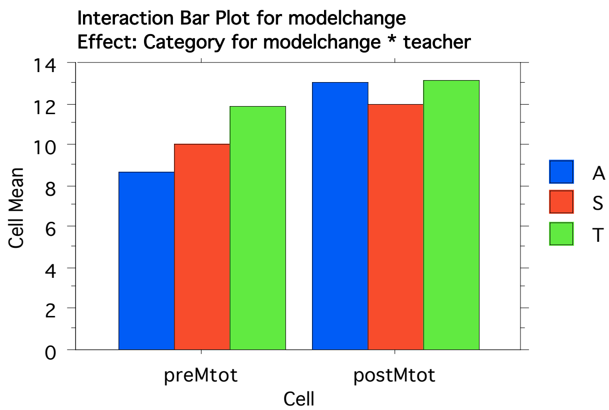
Appendix C4.1: Model Change Period 4

ANOVA Table for modelchange

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
teacher	2	63.678	31.839	2.807	.0681	5.614	.523
Subject(Group)	62	703.214	11.342				
Category for modelchange	1	190.437	190.437	35.768	<.0001	35.768	1.000
Category for modelchange * teacher	2	65.833	32.917	6.182	.0036	12.365	.889
Category for modelchange * Subject(Group)	62	330.098	5.324				

Means Table for modelchange
Effect: Category for modelchange * teacher

	Count	Mean	Std. Dev.	Std. Err.
A, preMtot	30	8.700	4.172	.762
A, postMtot	30	13.067	2.434	.444
S, preMtot	17	10.000	2.385	.578
S, postMtot	17	11.912	2.033	.493
T, preMtot	18	11.861	2.667	.629
T, postMtot	18	13.083	2.151	.507



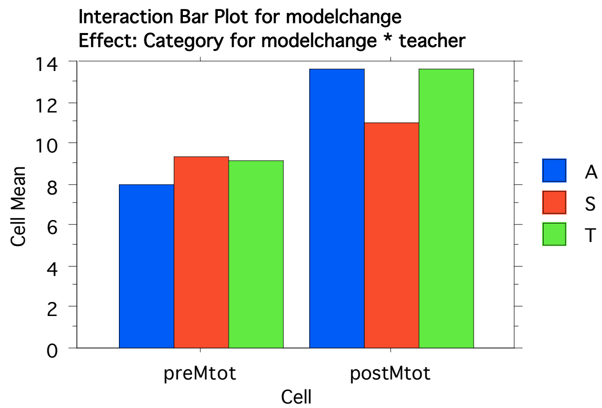
Fisher's PLSD for modelchange
Effect: teacher
Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value	
A, S	-.073	1.392	.9180	
A, T	-1.589	1.367	.0231	S
S, T	-1.516	1.551	.0552	

Appendix C5.1: Model Change Period 5

Means Table for modelchange
Effect: Category for modelchange * teacher

	Count	Mean	Std. Dev.	Std. Err.
A, preMtot	29	8.017	4.133	.767
A, postMtot	29	13.621	3.305	.614
S, preMtot	19	9.289	3.194	.733
S, postMtot	19	10.947	2.248	.516
T, preMtot	15	9.133	3.691	.953
T, postMtot	15	13.567	1.689	.436



ANOVA Table for modelchange

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
teacher	2	26.202	13.101	.840	.4368	1.680	.181
Subject(Group)	60	936.016	15.600				
Category for modelchange	1	444.676	444.676	75.513	<.0001	75.513	1.000
Category for modelchange * teacher	2	90.227	45.113	7.661	.0011	15.322	.950
Category for modelchange * Subject(Group)	60	353.325	5.889				

Fisher's PLSD for modelchange
Effect: teacher
Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value
A, S	.701	1.631	.3970
A, T	-.531	1.758	.5510
S, T	-1.232	1.909	.2040