A WISE Inquiry Project for Students' East-West Coast Collaboration[1]

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Abstract.

The paper will describe a large scale design study involving a total of 1100 middle and high school students from California and Massachusetts who collaborated on-line about plate tectonic activity in their respective location. The students, drawn from demographically diverse schools, collaborated on-line using WISE (Web-based Science Environment, Linn & Hsi, 2000). WISE is an integrated set of software resources 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 (Linn, 1998b; Linn & Hsi, 2000).

Following the WISE design framework, the two main pedagogical principles embodied in the present study were: Make thinking visible and help students learn from one another. In terms of **making thinking visible, we engaged students in two visual modes of representation**. First, using the drawing tool in WISE, students drew their models and used these models as artifacts for reiterative cycles of critique and model-revision. Secondly, students viewed a set of dynamic, runnable models of plate tectonic phenomena in order to better visualize the dynamic, causal, and temporal processes. In terms of **helping students learn from one another,** we engaged students in tasks in which they critiqued their learning partners' models from the opposite coast. We did this to provide students with an opportunity to both think deeply about the domain in order to do the critiques, as well as think about how models are used as tools for communication in science.

Data from 15 classrooms is described. Data analysis was focussed on primarily two areas: measuring content gains of the domain, and characterizing the nature of students' model critiques and subsequent revisions on the basis of these critiques. Results suggest that the east-west coast collaboration was successful in promoting content learning as measured by the content gains. Additionally, students' model-building and revision was influenced by the visualizations they viewed in the unit as well as by other content in the unit. Lastly, the model critiques of the students suggests that this is a successful way to promote reflection but that more scaffolding is necessary for the middle school students in order for students to successfully critique each others' work.

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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 authentic tasks that engage 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) and provide them with authentic tasks with science and with models that will deepen their understanding of science as a dynamic process. 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 (although these data are not discussed here).

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. Some of these key issues are: Does technology sufficiently take into account learner's needs and prior knowledge (Linn, 1999)? How does learning with technology differ from learning with conventional instructional media (Kozma, 1999; November, 1999)? and How can we use the technology effectively to promote deep learning in line with content, process, and epistemic goals? It is beyond the scope of one program of research to address all of these broad questions (for a thorough review of issues of learning with technology, see Dede, 1998). In the present research we will address how technology be effectively used to promote deep learning for content and model-based inquiry skills. In another session (26.40, Wednesday at 10:35), we address how technology can be effectively used in order to promote epistemic knowledge of the nature of science and of models in particular.

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

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

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.

• *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.

PRESENT RESEARCH

In the present research we designed a curriculum unit called "What's on your Plate?" around two of the WISE pedagogical principles, namely, Make Thinking Visible and Help Students Learn From One Another.

Domain Studied

The domain Plate Tectonics was chosen for two reasons. First, it is an excellent domain in which to investigate students' modeling skills 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[3]. Secondly, it is an excellent context in which to foster students' understanding of science and of models both because there are many excellent models in the domain 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. For example, the theory of Plate tectonics which has changed our entire concept of earth dynamics in the past 35-40 years was previously given barely a footnote in most introductory geology textbooks (Le Grand, 1991). As such, the theory of plate tectonics represents a major revolution in earth science (Plummer & McGeary, 1996).

Plate tectonics, which is typically covered in fifth or sixth grade and then again in eighth or ninth grade is representative of a difficult school science topic. It is difficult to learn for many reasons: 1) the earth's internal layers are outside our direct experience, 2) the size scale and the unobserved processes, e.g., convection, are difficult to understand (Ault, 1984; Gobert & Clement, 1994; 1999), 3) the time scale of geological processes is difficult for people to conceptualize since it surpasses our reference of a human lifetime (Jacobi et al., 1996), and 4) it involves the comprehension and integration of several different types of information, such as, spatial, causal, and dynamic (Gobert & Clement, 1994; 1999).

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[3] 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).

It is important to note that the goal in this program of research is to facilitate students' understanding of plate tectonics by means of qualitative models. As such, issues like whether radioactive decay in the mantle acts, in part, as a heat source in addition to the earth's core (Feather, Snyder, & Hesser, 1995) are not addressed.

Plate tectonics falls under the larger domain of Earth Science. More generally, the topic of learning in Earth Science has not been well studied, particularly when compared to students' learning and conceptions in the physical sciences (Stofflett, 1994). The lack of research on learning in the Earth Sciences is likely due to the fact that in the past, it has received much less emphasis than the Physical and Life Sciences. Now however, the National Science Education Standards (1996) are recognizing Earth Science as a necessary and important component of science training across elementary, middle, and high school levels and considered equivalent in importance to training in the Life and Physical sciences (AAAS, 1989, 1993).

As previously stated there have been relatively few studies of learning in the Earth Sciences. Of the studies that have been carried out, some of the sub-topics and issues that have been addressed are: the earth as a cosmic body (Vosniadou & Brewer, 1992; Nussbaum, 1979, Nussbaum & Novak, 1976); knowledge of rock-cycle processes (Stofflett, 1994); conceptions of earth and space as it relates to seasons and phases of the moon, (Schoon, 1992; Bisard et al, 1994); sea floor dynamics (Bencloski and Heyl, 1985); environmental problem-solving (Pinet et al., 1995); and knowledge of the earth's gravitational field (Arnold, Sarge, and Worrall, 1995). Research directly related to the causes of earthquakes has found serious misconceptions by both children (Ross & Shuell, 1993) as well as adults (Bezzi, 1989; Turner, Nigg, & Daz, 1986).

Background Research on Students' Models and Model-Based Learning

The proposed research draws on previous research on modeling in continental drift and plate tectonics with middle school students. Briefly studies conducted to date have addressed: the effects of a multimedia environment, CSILE (Scardamalia & Bereiter, 1991), on students' graphical and causal explanations of continental drift (Gobert et al., 1993); the nature of students' pre-instruction models of plate tectonics and learning difficulties encountered in this domain (Gobert, 2000); causal reasoning associated with models of varying levels of integration and the visual/spatial inferences afforded on the basis of models (Gobert, 2000); the benefits of student-generated diagrams versus summaries (Gobert & Clement, 1999) and student-generated diagrams versus explanations on rich learning (Gobert, 1997b); and the influence of students' epistemologies of models on learning in this domain (Gobert & Discenna, 1997).

The present work builds on and extends the author's existing research in order to design, test, and refine rich model-based, inquiry tasks for middle and high school students for learning in the domain of plate tectonics. In order to promote students' content knowledge, inquiry skills, and epistemological knowledge, 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 inquiry in science education. Lastly, the unit was designed to promote students' understanding of the nature of science and of scientific models. It is also important to note that 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 two pedagogical principles upon which this work is principally based are: Make Thinking Visible and Help Students Learn from Each Other. Each will be discussed in turn.

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 per critique, 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 terms of **helping students learn from one another,** we engaged students in tasks in which they critiqued their learning partners' models from the opposite coast. We did this to provide students with an opportunity to both think deeply about the domain in order to do the critiques, as well as think about how models are used as tools for communication in science.

The "What's on your plate?" unit the students are engaged in model-based inquiry activities (the topic of the present paper) and tasks to learn from one another 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: the 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), 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 reflect 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 8-10 for 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 directs 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)[4].. Our research 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 domain?

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, and their understanding of the nature of models both before and after the unit (not discussed here); the same test was given before and after. The pre- and post-test items can be seen in Appendix B.

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

RESULTS & DISCUSSION

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.

Data analysis. The data analysis is described in two parts. The first part describes the increases made in students' understanding of the content as measured by pre-post gains. The second part describes students' critique of their peers' models, and the resulting model revision as a result of peer critique as well as content they learned in the unit.

Part. 1: Analysis of Variance of WISE periods 1-5. Analysis of variance was used on the total pre- and post-score on the content 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' understanding of the domain (as measured by the post-test) 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 content survey after the unit then they did before the unit. In each WISE period, collapsing over teacher, the effect is significant. See Appendices C1.2, 2.2,3.2,4.2,and 5.2 for the relevant anova table, tables of means and standard deviations, and figures. Each finding will be described briefly in turn.

WISE Period 1.

In WISE Period 1, anova revealed that the post-test scores for content knowledge were significantly greater than the pre-test scores (collapsing over teacher) ($F=44.982$, $p<.0001$) and that there was a content by teacher interaction ($F=3.891$, $p=.0257$). No post-hoc tests were significant for this analysis indicating that the pattern of change from pre- to post-test was not significantly different across the three teachers . See Appendix C1.2 and C1.3 for these tables and figure.

In WISE Period 2, anova revealed that the post-test scores for content knowledge were significantly greater than the pre-test scores (collapsing over teacher) ($F=39.473$, $p<.0001$) and that there was a content by teacher interaction ($F=6.617$, $p=.0025$). Fisher's PLSD post-hoc analyses indicated that there was a significantly different pattern between the pre- and post-test scores for Teacher A and Teacher S, and the scores for Teacher A and Teacher T. See Appendix C2.2 and C2.3 for these tables and figure.

In WISE Period 3, anova revealed that the post-test scores for content knowledge were significantly greater than the pre-test scores (collapsing over teacher) ($F=26.654$, $p<.0001$) and that there was a content by teacher interaction ($F=15.480$, $p<.0001$). Fisher's PLSD post-hoc analyses indicated that there was a significantly different pattern between the pre- and post-test scores for Teacher A and Teacher T. See Appendix C3.2 and C3.3 for these tables and figure.

In WISE Period 4, anova revealed that the post-test scores for content knowledge were significantly greater than the pre-test scores (collapsing over teacher) ($F=25.019$, $p<.0001$) and that there was a content by teacher interaction ($F=5.657$, $p=.0055$). Fisher's PLSD post-hoc analyses indicated that there was a significantly different pattern between the pre- and post-test scores for Teacher A and Teacher T. See Appendix C4.2 ad C4.3 for these tables and figure.

In WISE Period 5, anova revealed that the post-test scores for content knowledge were significantly greater than the pre-test scores (collapsing over teacher) ($F=18.220$, $p<.0001$) and that there was a content by teacher interaction ($F=11.916$, $p<.0001$). Fisher's PLSD post-hoc analyses indicated that there was a significantly different pattern between the pre- and post-test scores for Teacher A and Teacher S, and between the scores for Teacher A and Teacher T. See Appendix C5.2 and C5.3 for these tables and figure.

Discussion of Data Analysis for Part 1.

In all of the WISE periods, the students made a significant gain on the post-test collapsing over teacher, meaning that all WISE periods acquired knowledge during the implementation of the "What's on your plate?" unit.

In all of the WISE periods except for period 1, there was a significant teacher by gain interaction. In the following periods a statistically significant teacher by gain interaction was found (these data can be seen in figures in Appendices C1.2, 2.2,3.2,4.2,and 5.2).

Table 1.
Significant Teacher by Gain Interactions

WISE Period 2	Students of Teacher A made greater gains than students of Teachers S or T
WISE Period 3	Students of Teacher A made greater gains than students of Teacher T
WISE Period 4	Students of Teacher A made greater gains than students of Teacher T
WISE Period 5	Students of Teacher A made greater gains than students of Teachers S or T

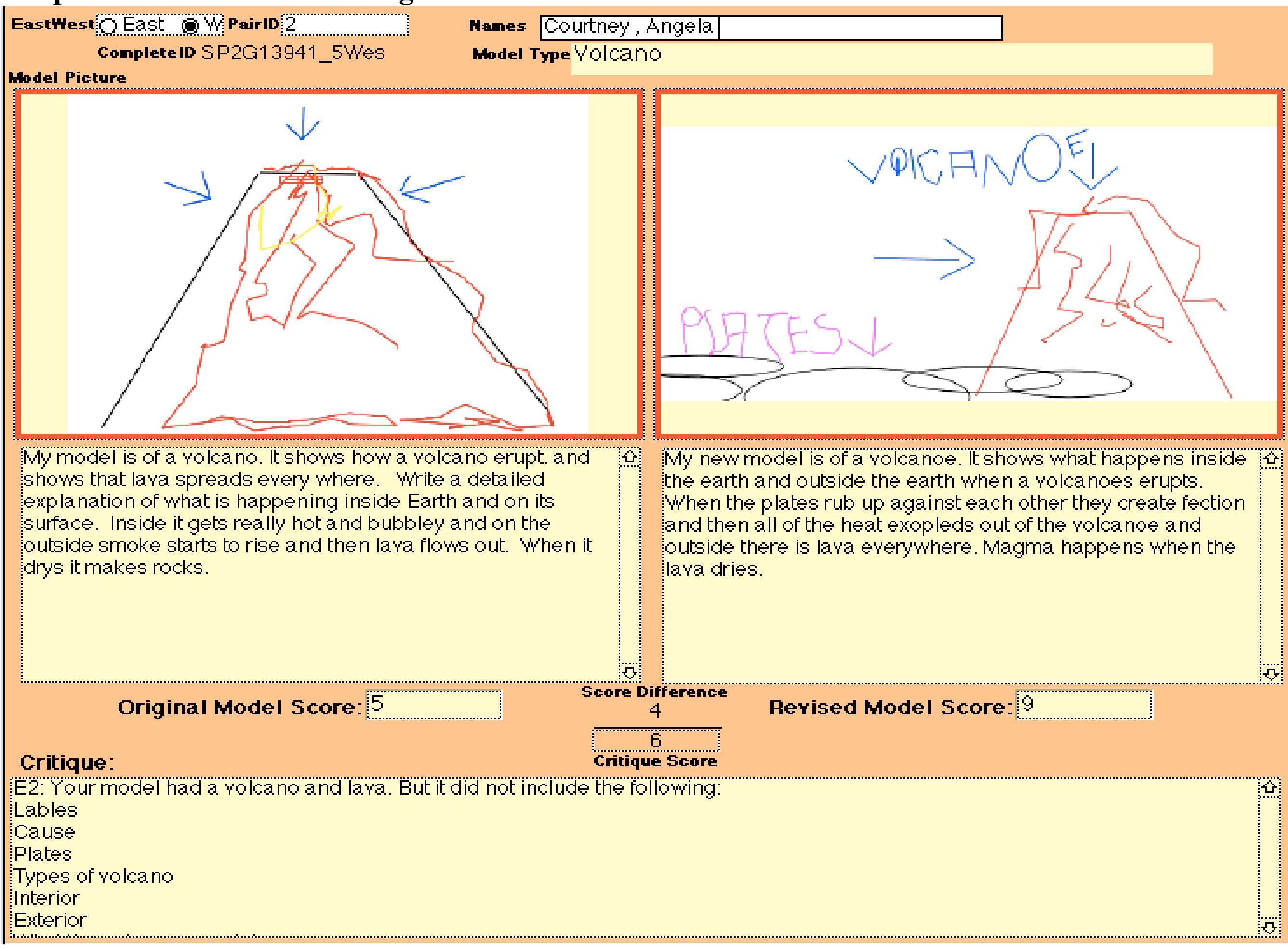
Briefly, what is important to note about these data was that the pre-test scores for Teacher A's classes were, in all classes, lower than those of Teacher S or T with the exception of Period 1 where all the groups were similar in their pre-test score (See Appendices C1.2, 2.2,3.2,4.2,and 5.2 for these data). What the teacher by gain interaction suggests then is that the students who had the least prior knowledge gained the most content knowledge from the unit and from their peers. Although since the unit contained a great deal of content knowledge as well, students' learning gains on both coasts could be due to peer interaction, the content in the unit, or some combination of the two. This research cannot and was not designed to empirically tease out the relative gain of the two possible causal factors.

Part 2

From this large data set, we selected some examples to get a sense of the types of critiques students were writing for their peers and how these critiques influenced students' model revision.

In the following examples, the model on the left is the students' original model and explanation. On the bottom under "Critique" is their opposite coast learning partners' critique of the model. On the right are students' revised models and revised explanations.

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



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. (For an example of the coding scheme for volcanic eruption, see Appendix B.2). 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 plates and 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 plate convergence [5]. 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.

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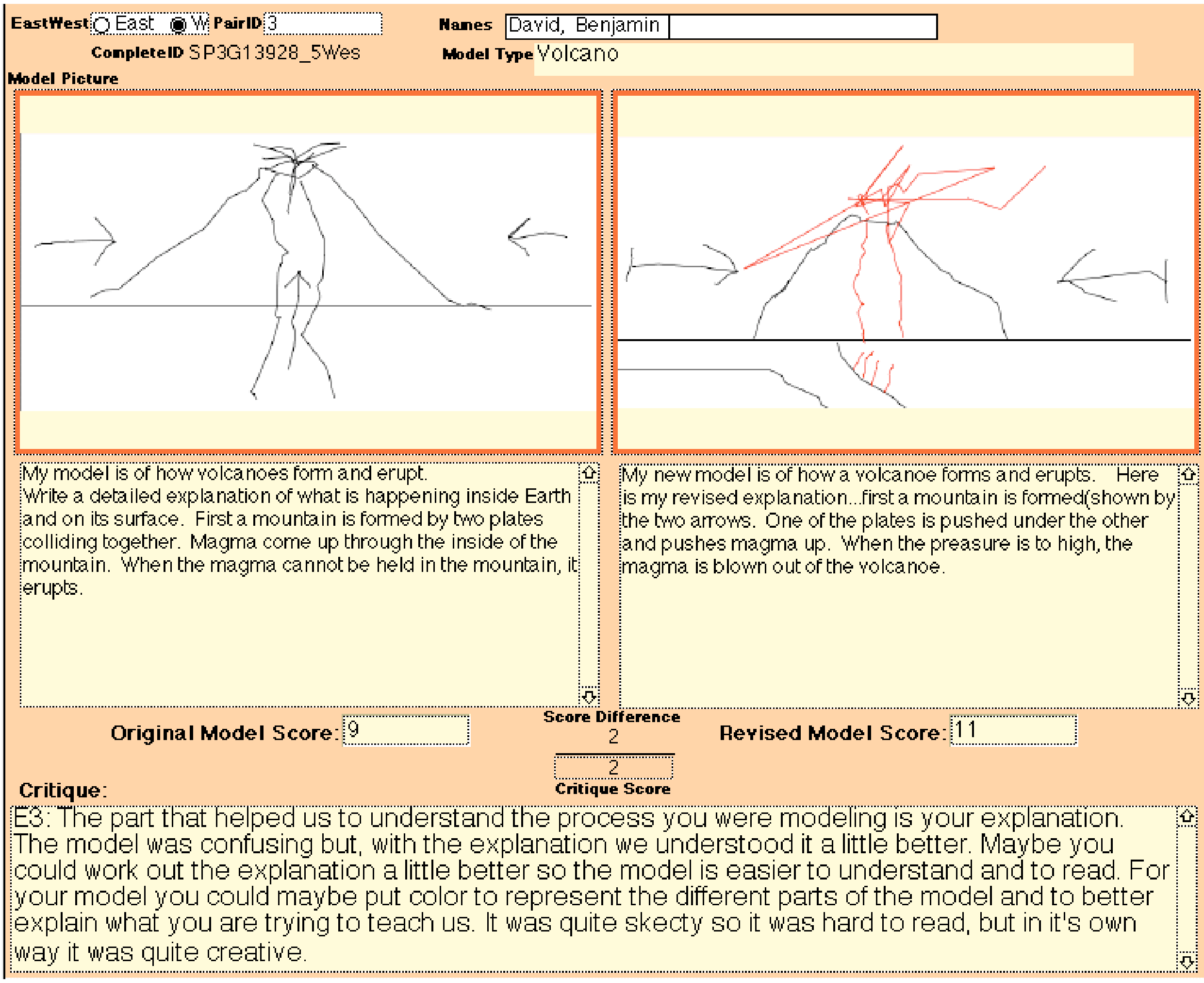
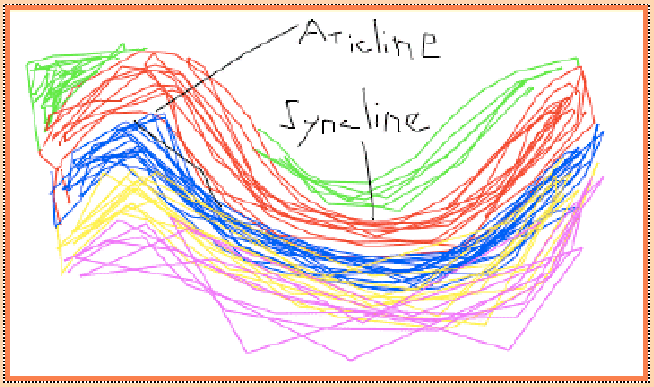


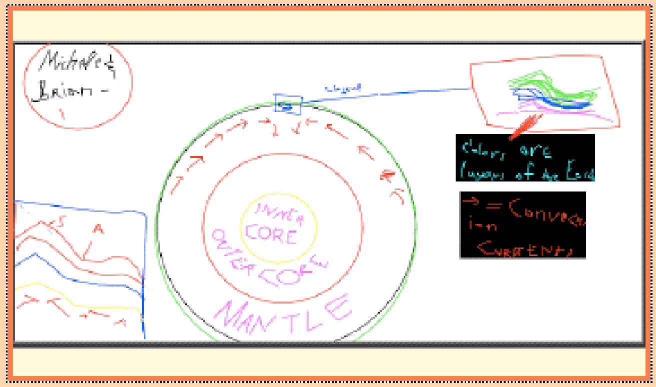
In this example the students' model represents a misconception, i.e., that a mountain is formed and fills up with lava and when it fills up, it erupts. Unfortunately, the learning partners' critique did not include much information upon which a revision could be based; this is possibly due to them not 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 plate subduction and magma movement as a causal mechanism in how volcanoes 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, Brian

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.

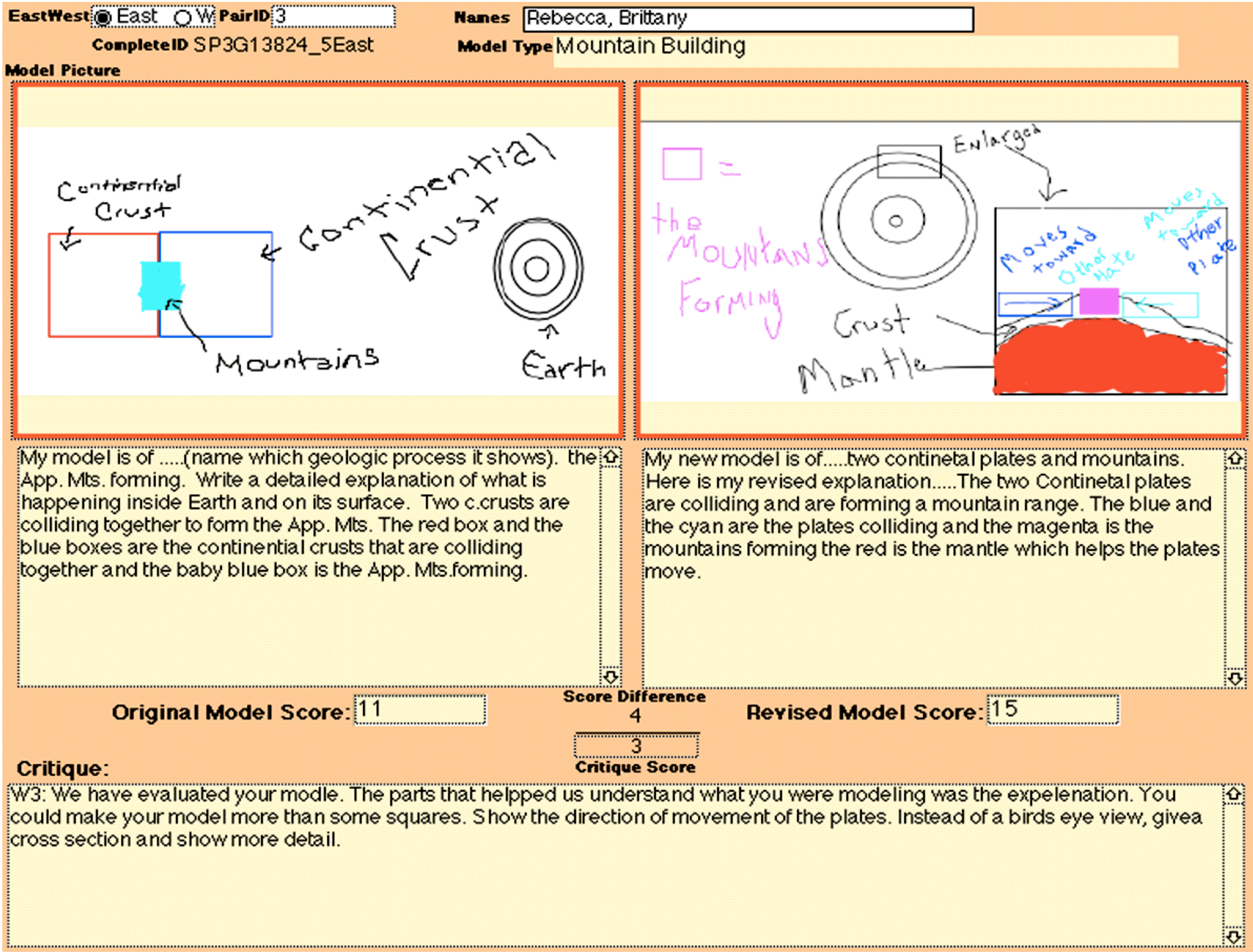
Original Model Score: 4 **Score Difference** 10 **Revised Model Score:** 14

1 **Critique Score**

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, the relationship of the convection to the crustal movement and the location of the convection in the correct layers of the earth (the mantle), in their revised model represents a significant advance from their earlier model (Gobert, 2000).



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. In addition the students have added the mantle as a causal mechanism. 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.

SUMMARY & CONCLUSIONS

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 domain, as evidenced by significantly higher scores on the post-test for each of the five WISE periods.

The data also suggests that the unit benefited those who knew little about the domain. For these students in particular, the curriculum and peer learning appeared to be particularly useful.

A subset of data was analyzed in order to get a sense of the ways in which students' critiques and the content in the unit were influential in promoting model revision in their learning partners. A set of examples were provided, many of which showed gains from their original models. The students read a section which introduced models, their purpose, and how to evaluate them. In addition we integrated prompts in WISE for students to evaluate their learning partners' models. These included prompts to promote students' thinking about their learning partners' models as an explanation the causal system, as well as the model as an effective tool for someone to learn with. The model critiques of the students suggest that this may a useful way to promote deeper content understanding. More analysis of the existing data is needed in order to tease out the relative contributions of the content in the unit and the learning partners' critiques on model revision.

This research utilized a state-of the art science learning environment, WISE, to promote deep learning of subject-matter in plate tectonics and model-based inquiry skills involving model critiquing and revision. This research on modeling fits within a current vein of science education which seeks to promote integrated understanding by use of model-based tasks. In most of these programs to date, 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). Having students critique each others' models is a novel approach to both deepening their understanding of the content (so that they may critique others' work) as well as fostering an understanding of what models are and how they are used as learning tools. It is believed that having students construct, reason with, and critique each others' models engages them in authentic scientific inquiry, and can significantly impact lifelong learning and scientific literacy (Linn & Muilenberg, 1996).

REFERENCES

American Association for the Advancement of Science. (1989). *Science For All Americans*: *Project 2061.* Washington, D.C.: American Association for the Advancement of Science.

American Association for the Advancement of Science. (1993). *Benchmarks for Science Literacy*: 1993. New York Oxford: Oxford University Press.

Arnold, P., Sarge, A., & Worrall, L. (1995). Children's knowledge of the earth's shape and its gravitational field. *International Journal of Science Education,* 17(5), 635-641.

Ault, Jr., C. R. (1984). The everyday perspective and exceedingly unobvious meaning. *Journal of Geological Education,* 32, 89-91.

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.

Bezzi, A. (July, 1989). *Geology and Society: A survey on pupils' ideas as an instance of a broader prospect for educational research in earth science.* Paper presented at the 28th International Geological Congress, Washington, D.C.

Bisard, W. J., Aron, R. H., Francek, M. & Nelson, B. D. (1994). Assessing selected physical science and earth science misconceptions of middle school through university pre-service teachers. *Journal of College Science Teaching,* September/October, 38-42.

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.

Clement, J., Brown, B., & Zietsman, A. (1989). Not all preconceptions are misconceptions: Finding "anchoring conceptions" for grounding instruction on students' intuitions. *International Journal of Science Education,* 11, 554-565.

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

Dede, C. (1998). *Learning with technology*, Dede, C. (Ed.), Alexandria, VA: Association for Supervision and Curriculum Development.

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.

Frederiksen, J., White, B., & Gutwill, J. (1999). Dynamic mental models in learning science: The importance of constructing derivational linkages among models. To appear to Journal of Research in Science Teaching.

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. & Clement, J. (1994). *Promoting causal model construction in science through student-generated diagrams*. Presented at the Annual Meeting of the American Educational Research Association, April 4-8. New Orleans, LA.

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., 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.

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. (1998). *A typology of models for plate tectonics: Inferential power and barriers to understanding.* Presented at the Annual Meeting of the American Educational Research Association, April 13-18, San Diego, CA.

Gobert, J. (1999). A typology of models for plate tectonics: Inferential power and barriers to understanding. Manuscript accepted for publication in the *International Journal of Science Education*.

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.

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.

Inhelder, B. & Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence*. New York: Basic Books.

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.

Jacobi, D., Bergeron, A., & Malvesy, T. (1996). The popularization of plate tectonics: presenting the concepts of dynamics and time, *Public Understanding in Science,* 5, 75-100.

Kozma, R. (1999). *Discussant for Current Applications of Instructional Theory and Design in Technology*, Symposium presented at the Annual Meeting of the American Educational Research Association, April 19-23, Montreal, Canada.

Le Grand, H. E. (1991). *Drifting continents and shifting theories*. Cambridge, UK: Cambridge University Press.

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. (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., 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.

Monaghan, J. & Clement, J. (1995*). Visual and numeric models of Galilean relativity used by students interacting with computer simulations*. Presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA.

National Research Council. (1996). *National Science Education Standards*: 1996. Washington, D.C.: National Academy Press.

Nussbaum, J. (1979). Childrens conceptions of the earth as a cosmic body: a cross age study. *Science Education,* 63, 83-93.

Nussbaum, J. & Novak, J. D. (1976). An assessment of children's concepts of the earth utilizing structured interviews. *Science Education,* 60, 535-550.

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.

Pinet, P. R. (1995). Rediscovering geological principles by collaborative learning. *Journal of Geological Education,* 43, 371-376.

Ploger, D. and Della Vedova, T. (1999). Dynamic Charts in the Elementary Classroom. *Learning and Leading with Technology* 26, 38-41.

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.

Ross, K. & Shuell, T. (1993). Children's beliefs about earthquakes. *Science Education*, 77, 191-205.

Scardamalia & Bereiter, (1991). High levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *Journal of the Learning Sciences*, 1(1), 37-68.

Schoon, K. J. (1992). Students' Alternative Conceptions of Earth and Space. *Journal of Geological Education,* 40. 209-214.

Schwarz, C. & White, B. (1999). *What do seventh 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.

Stofflett, R. (1994). Conceptual change in elementary school teacher candidate knowledge of rock-cycle processes. *Journal of Geological Education,* 42, 494-500.

Turner, R. H., Nigg, J. M., & Daz, D. H. (1986). *Waiting for disaster: Earthquake watch in California*. Berkeley, CA: University of California.

Vosniadou, S. & Brewer, W. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, 24, 535-585.

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

Pre- and post test for content & understanding of models

Content Assessment

1) Name all the geologic processes that occur along convergent plate boundaries (plates moving together).
2) Name all the geologic processes that occur along divergent plate boundaries (plates moving apart).
3) Name all the geologic processes that occur along transform plate boundaries (plates sliding past each other).
4) Explain why rock from the middle of the North American Continent is older than rock from the floor of the Atlantic Ocean.
5) Explain how the Himalayan mountains were formed.
6) Explain what volcanic eruption, mountain formation, earthquakes, and sea floor spreading have in common in terms of what causes them?

Understanding of Models Assessment

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

Appendix B.2

Coding Protocol for Models of Volcanic Eruption

Scoring of Spatial/Static Components

crust :		
	LOC: on surface	**1 point**
	PART: plates	**2 points**
	ATT: includes continents and/or ocean floor	**1 point**
	• if plates are shown in mantle instead of crust:	**1 point**
	If plates are shown incorrectly spatially no points	
mantle:		
	PART: magma	**2 points**
	• if magma is mentioned but not mantle:	**1 point**
	• if mantle layer is called magma not mantle:	**1 point**
	LOC: below crust	**1 point**
	ATT: magma is liquid	**1 point**
	ATT: magma is hot	**1 point**
core:		
	LOC: center of earth	**1 point**
	If core is shown below mantle but not as center of earth	**.5 points.**
	ATT: hot mass	**1 point**
	PART: has inner core	**1 point**
		total= 15.5 points

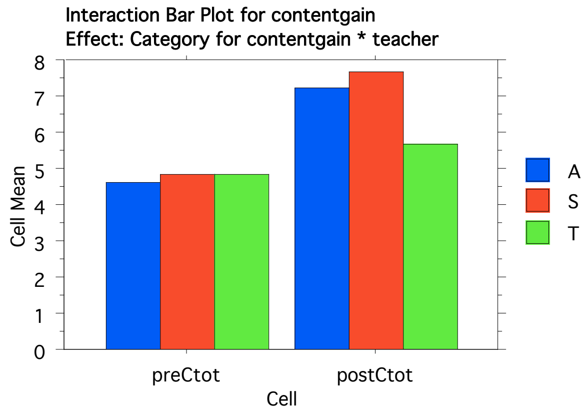
Scoring of Causal/Dynamic Components

a. magma in the mantle is moving in a circular pattern (convection)	**2 points**
b. heat/magma currents push on plates	**2 points**
c. plates move	**2 points**
d. If circulation pattern relates to direction of plate movement	**2 points**
e. One plate subducts below another plate or plates diverge	**2 points**
f. magma/lava rises (from mantle not from core)	**2 points**
g. magma/lava rises above surface	**2 points**
h. magma hardens and rocks rock	**2 points**
	Total: 14 points

Appendix C1.2 Content Change Period 1

Means Table for contentgain
Effect: Category for contentgain * teacher

	Count	Mean	Std. Dev.	Std. Err.
A, preCtot	29	4.621	2.665	.495
A, postCtot	29	7.207	2.808	.521
S, preCtot	17	4.824	2.243	.544
S, postCtot	17	7.647	1.801	.437
T, preCtot	18	4.861	1.885	.444
T, postCtot	18	5.681	2.313	.545



ANOVA Table for contentgain

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
teacher	2	17.231	8.615	.998	.3745	1.996	.208
Subject(Group)	61	526.577	8.632				
Category for contentgain	1	130.331	130.331	44.982	<.0001	44.982	1.000
Category for contentgain * teacher	2	22.548	11.274	3.891	.0257	7.782	.680
Category for contentgain * Subject(Group)	61	176.740	2.897				

Appendix C1.2 Post Test Change Period 1

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

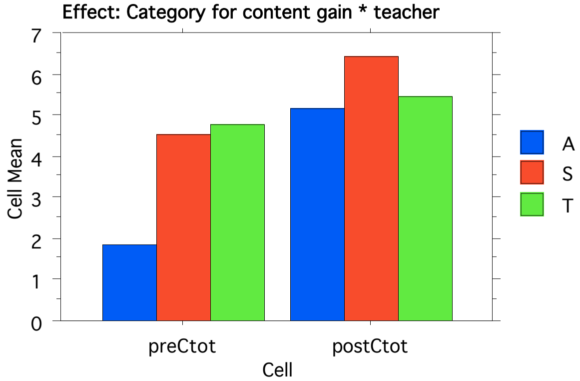
	Mean Diff.	Crit. Diff.	P-Value
A, S	-.322	1.130	.5745
A, T	.643	1.110	.2540
S, T	.964	1.252	.1298

Appendix C2.2 Content Change Period 2

Means Table for content gain
Effect: Category for content gain * teacher

	Count	Mean	Std. Dev.	Std. Err.
A, preCtot	29	1.828	1.649	.306
A, postCtot	29	5.172	2.550	.474
S, preCtot	17	4.529	3.243	.786
S, postCtot	17	6.412	3.641	.883
T, preCtot	17	4.750	3.077	.746
T, postCtot	17	5.456	3.192	.774

Interaction Bar Plot for content gain
Effect: Category for content gain * teacher



ANOVA Table for content gain

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
teacher	2	102.229	51.114	3.946	.0246	7.891	.687
Subject(Group)	60	777.298	12.955				
Category for content gain	1	115.695	115.695	39.473	<.0001	39.473	1.000
Category for content gain * teacher	2	38.791	19.396	6.617	.0025	13.235	.911
Category for content gain * Subject(Group)	60	175.860	2.931				

Appendix C2.3 Post Test Change Period 2

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

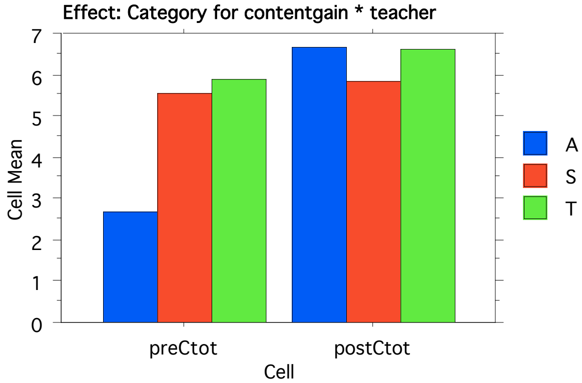
	Mean Diff.	Crit. Diff.	P-Value	
A, S	-1.971	1.307	.0034	S
A, T	-1.603	1.307	.0167	S
S, T	.368	1.468	.6209	

Appendix C3.2 Content Change Period 3

Means Table for contentgain
Effect: Category for contentgain * teacher

	Count	Mean	Std. Dev.	Std. Err.
A, preCtot	30	2.667	2.264	.413
A, postCtot	30	6.667	3.066	.560
S, preCtot	17	5.529	3.085	.748
S, postCtot	17	5.824	2.811	.682
T, preCtot	18	5.889	2.530	.596
T, postCtot	18	6.611	2.820	.665

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



ANOVA Table for contentgain

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
teacher	2	60.752	30.376	2.525	.0883	5.050	.476
Subject(Group)	62	745.837	12.030				
Category for contentgain	1	85.178	85.178	26.654	<.0001	26.654	1.000
Category for contentgain * teacher	2	98.937	49.469	15.480	<.0001	30.960	1.000
Category for contentgain * Subject(Group)	62	198.133	3.196				

Appendix C3.3 Post Test Change Period 3

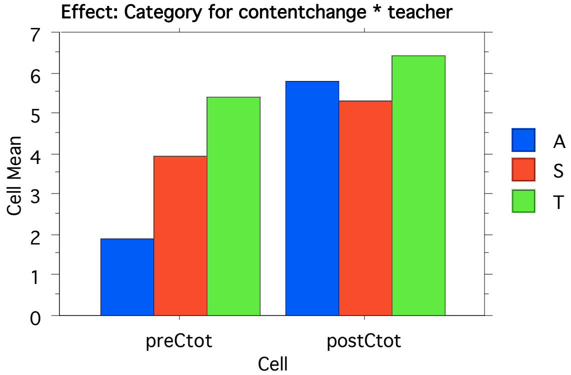
Fisher's PLSD for contentgain
Effect: teacher
Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value	
A, S	-1.010	1.300	.1267	
A, T	-1.583	1.277	.0155	S
S, T	-.574	1.448	.4347	

Appendix C4.2 Post Test Change Period 4

Means Table for contentchange
Effect: Category for contentchange * teacher

	Count	Mean	Std. Dev.	Std. Err.
A, preCtot	30	1.900	2.383	.435
A, postCtot	30	5.767	3.626	.662
S, preCtot	17	3.941	2.461	.597
S, postCtot	17	5.294	3.788	.919
T, preCtot	18	5.417	2.680	.632
T, postCtot	18	6.417	2.503	.590



ANOVA Table for contentchange

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
teacher	2	97.656	48.828	3.898	.0254	7.796	.682
Subject(Group)	62	776.675	12.527				
Category for contentchange	1	130.942	130.942	25.019	<.0001	25.019	1.000
Category for contentchange * teacher	2	59.218	29.609	5.657	.0055	11.315	.855
Category for contentchange * Subject(Group)	62	324.487	5.234				

Appendix C4.3 Post Test Change Period 4

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

	Mean Diff.	Crit. Diff.	P-Value	
A, S	-.784	1.385	.2645	
A, T	-2.083	1.360	.0030	S
S, T	-1.299	1.543	.0982	

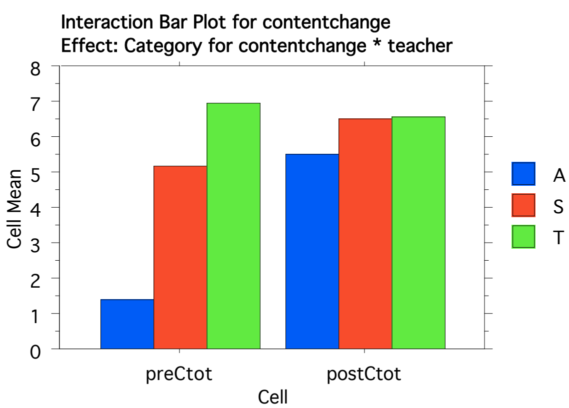
Appendix C5.2 Post Test Change Period 5

ANOVA Table for contentchange

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
teacher	2	256.450	128.225	13.509	<.0001	27.018	.999
Subject(Group)	60	569.514	9.492				
Category for contentchange	1	82.505	82.505	18.220	<.0001	18.220	.994
Category for contentchange * teacher	2	107.916	53.958	11.916	<.0001	23.832	.997
Category for contentchange * Subject(Group)	60	271.692	4.528				

Means Table for contentchange
Effect: Category for contentchange * teacher

	Count	Mean	Std. Dev.	Std. Err.
A, preCtot	29	1.414	1.376	.256
A, postCtot	29	5.483	3.043	.565
S, preCtot	19	5.158	2.873	.659
S, postCtot	19	6.526	2.796	.641
T, preCtot	15	6.933	3.644	.941
T, postCtot	15	6.533	1.959	.506



Appendix C5.3 Post Test Change Period 5

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

	Mean Diff.	Crit. Diff.	P-Value	
A, S	-2.394	1.236	.0002	S
A, T	-3.285	1.331	<.0001	S
S, T	-.891	1.446	.2248	