Exploring Elementary Students' Learning of Astronomy Through Model Building

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ABSTRACT

The purpose of this work is to explore learning and instruction within a project-based technology-rich fifth grade science classroom. Specifically, students worked in teams using three-dimensional (3-D) modeling software to construct 3-D models of the Earth-Moon-Sun system. For this study, naturalistic inquiry was used to build a holistic account of student activity. In particular, we examined students' difficulties, challenges, and successes as they constructed models of astronomical phenomena. Our findings are based on a synthesis of case studies of each student team as they constructed their models. Specifically, we characterize how students asked questions, planned, designed, constructed, evaluated and drew conclusions from their models. Our findings suggest that young students can build sophisticated models which in turn foster discussion and exploration of complex scientific concepts. Our findings also suggest that students traverse stages of model development initially simply following directions laid out by the instructor, but later as their model's complexity increase move to learning with their model rather than simply about their model.

INTRODUCTION

Models are not a new instructional technique, rather they have a long and distinguished tradition in fostering learning. Teachers have used spheres of varying sizes and colors to model the solar system, as well as balls and sticks to help students visualize the relationships between the constituent atoms of a molecule. More informally, children naturally construct models using toys, blocks, or whatever they have at hand to represent and come to terms with the world around them. In other words, models allow for the understanding of complex problems through simplification and idealization of the real world into more manageable abstractions. For example, scientists build simplified models to test theories and to improve their understanding of complex systems. Due to their simplicity, when compared to the real world phenomena to which they are related, these models entail a number of assumptions; however, a model can be a powerful learning tool for helping a person understand complex systems.

Current computer advances are transforming science and creating exciting new opportunities for learning about science through the use of models (Sabelli, 1994; Stratford, 1997; Stratford, Krajcik; & Soloway, 1998). In particular, the methods and processes of inquiry through computational-modeling bring new challenges for science educators (Jackson, Stratford, Krajick, & Soloway, 1998; Lehrer, Horvath, & Schauble, 1994). From a learning perspective, the act of modeling allows students to engage in a design process that begins with a set of tentatively accepted theories that can evolve into coherent understandings represented in their models (Roth, 1996; Sabelli, 1994). As a result, computational modeling activities have become more commonplace in inquiry-based science classrooms, in part because educators have recognized that an important activity of scientists is building, designing, testing, and evaluating models of natural phenomena (Hestenes, 1992).

Despite this increased interest in supporting students in building and revising computational models, a great deal remains to be understood about the ways in which students construct understandings of natural phenomena when making models. For example, when students engage in modeling activities, what kinds of models can students really construct and does modeling support students in asking meaningful questions? Also, what process do students actually go through when constructing computer models? In this manuscript, we explore these three questions.

THEORETICAL FRAMEWORK

According to Stratford, Krajcik, and Soloway (1998) a model is a scientific construct designed to imitate a real world phenomenon and modeling is the act of creating or revising a model. Webb's (1993) definition is more complete in that she described a model as a formal representation of a problem, process, idea or system and it is never an exact replica, but represents one or more aspects of the structure, properties or behavior of what is being modeled. In other words, a model can instantiate itself in several forms including diagrams, formulae (Newton's laws), an actual physical construction, or a set of logical statements. White (1993) suggests that models allow the development of a simplified representation of a phenomenon to be produced and therefore allows for the concentrated study on special features of that phenomenon. A characteristic of these definitions is their focus on the fact that models are used to simplify and idealize a complex real-world phenomenon in order to gain a better understanding.

Modeling activities are becoming increasingly important in learning and teaching science because of four converging trends: (a) the adoption of new standards for mathematics and science education for all students that emphasis the inclusion of modeling activities in K-12 contexts; (b) the continued explosion of scientific information and its accessibility through computer networks (e.g., the World Wide Web); (c) the development of powerful computer modeling tools made possible by increased computational capabilities in the classroom; and (d) the recognition by educators that a major activity of scientists is building, designing, testing, and evaluating models of natural phenomena (Hestenes, 1992; NRC, 1996; Lehrer, Horvath, & Schauble, 1994; Sabelli, 1994; Stratford, 1997). In fact, the scientific endeavor itself has been described at its essence as a process of designing and constructing models for their conceptual, theoretical, and predictive value (Penner, Lehrer, & Schauble, 1998; Stewart, Hafner, Johnson, & Finkel, 1992).

Only recently have the tools practicing scientists use to build computational models, which enable them to visualize complex concepts and phenomena, become available to students. A computational model is the embodiment of a concrete concept or theory, which provides a structure through which students can explore, experiment, visualize, and test their understandings (Lehrer, et al., 1994). Therefore, within the context of building models in the classroom students can “do science” rather than being expected to absorb transmitted information about science, because they are using similar techniques and tools employed by many scientists to investigate natural phenomena (Penner, et. al., 1998; Stewart, et al., 1992). Many students now have opportunities to design and construct models, and engage in computational modeling as inquiry approaches to learning (Sabelli, 1994; Stratford, Krajcik, & Soloway, 1998).

Currently, many modeling initiatives support students in designing their own models, rather than educators providing students with pre-developed models by experts (Jackson, Stratford, Krajcik, & Soloway, 1998; Penner, et al., 1998; Stewart, et al., 1992). When viewed from a learning perspective, the process of designing models affords students the opportunity to engage in a scientific process that begins with a set of tentatively accepted theories that co-evolve with the students' emerging understanding and in turn is transformed into artifacts that embody the students' design processes, as well as their understandings (Roth, 1996; Sabelli, 1994). During this modeling process, conversations unfold among students, students and the teacher, the students and their models, and the students and the materials of their work as students attempt to create meaning through and from their constructions (Roth, 1996). These conversations guide the students in their examination of their model design process by evaluating their design methodologies, their justifications and arguments, as well as their existing perceptions, beliefs and understandings (Perkins, 1986; Peterson, et al., 1987). As such, students move beyond serving as receptacles for information and facts, and become immersed in an iterative design process through which their understandings inform the development of their models, and the evaluation and testing of their models inform their evolving understandings (Penner, Giles, Lehrer, Schauble, 1997).

ASTRONOMY LEARNING

According to the National Science Education Content Standards (National Research Council, 1996) students in grades five through eight should have a clear idea about the direction of gravity when standing on the Earth, the shape of the Earth, and relative size and distance between the Earth, Sun and Moon. However, several studies have shown that most students in these grades are far from such a robust understanding (Barnett & Morran, in press; Baxter, 1989; Stahly, Krockover, & Shepardson, 1999). In fact, according to the Pfundt and Duit (1998) bibliography there have been over 116 studies reporting that students of all ages enter science classrooms with impoverished or contrary explanations of astronomical phenomenon that are in conflict with the explanation accepted by the scientific community. These understandings have been described by many terms including misconceptions, pre-conceptions, alternative conceptions and alternative frameworks (Wandersee, Mintzes, & Novak, 1994). In this manuscript we will refer to these views as alternative frameworks, because understanding of many astronomy concepts are frequently embedded within a larger structure (Smith, diSessa, & Roschelle, 1993).

This difficulty in developing an understanding of astronomical concepts arises, in part, because the science of astronomy requires students to develop an understanding of the complex relationships and dynamics between objects in 3-D space. In addition, students are required to examine, mentally or otherwise, objects and events from multiple perspectives (Parker & Heywood, 1998). However, despite the 3-D nature of astronomy, most resources available to students are in the form of 2-D charts and images within textbooks that attempt to emulate astronomical phenomena from different 3-D perspectives. Additionally, students have only one perspective in which to develop their understanding of the astronomy concepts—namely from that of the Earth's perspective. As a result, developing learning activities that afford students with opportunities to examine astronomical phenomena from different perspectives has traditionally been difficult. Students simply cannot visit the Moon and look back at the Earth to observe the effects of the change in their perspective (i.e. Does the Earth have phases when viewed from the Moon?).

ENABLING TECHNOLOGY

The creation of 3-D computational models has traditionally required advanced computer hardware and programming skills. However, recent advances in 3-D modeling wysiwig (what you see is what you get) editors, coupled with the declining cost and growing power of personal computers has opened a variety of opportunities for students to build complex 3-D models. In the VSS course, students constructed their models using Virtual Reality Modeling Language (VRML). VRML[1] is similar to HTML in that it is a language used for viewing Virtual Reality worlds on the World Wide Web (WWW). Additionally, VRML is platform independent and is easily viewed over the Web using a free plug-in and a web browser. One distinct advantage of using VRML, instead of other software packages, is the ease of portability of student work to the

[1] VRML has recently been supplanted with the Web3D standard which combines elements of VRML and JAVA 3D.

WWW. This portability serves as a large motivating factor for the students because they are aware that their models can be viewed by their peers and critiqued by anyone who has access to the WWW. In the VSS course all student models are posted on the course website at http://vss.crlt.indiana.edu.

Rather than programming their models by hand, the VSS course students use a wysiwig VRML editor, CosmoWorlds. This product reduces the tedious coding of VRML to a few mouse clicks. Instead of typing in abstract commands to create an earthlike object, a student can simply drag a sphere from the object toolbox into the workspace and resize, reorient, change it's lighting, and texture the sphere to look like the Earth all within a short period of time and few mouse clicks (see Figure 1). This procedure takes the student a few seconds, freeing him or her to concentrate on learning astronomy instead of struggling to learn the syntax and structure of programming VRML.

Most beginning astronomy students experience difficulty in developing an understanding of astronomical phenomenon that requires them to change their frame of reference. This difficulty arises, in part, from the inability of most students to visualize the complex spatial positions of the Earth, Sun and Moon, and their insufficient experience in solving and investigating problems that require a change in reference frame. One of the strengths of VRML is it allows for the use of viewpoints. Viewpoints refer to perspectives or "camera positions" that can be placed within a VRML model. These viewpoints allow viewers of the model to immediately shift their frame of reference to various locations within the model and examine the model from the new perspective. This functionality provided by VRML opens many learning opportunities that are not normally available to many beginning astronomy students. For example, if a student wished to view the Earth from the Moon he or she would traditionally be relegated to viewing static pictures that show the Earth from the Moon. However, by using viewpoints in their 3-D models a student can place a viewpoint on the Moon and observe the Earth, determine whether the Earth has phases and visualize other astronomical concepts that can be better understood by exploring multiple perspectives (i.e. Does the Sun rise on the Moon?).

STUDY CONTEXT

The design of this science curriculum module is based on our previous research and the development work of the Virtual Solar System (VSS) Project (Barnett, Barab, & Hay, 2001;

Barab, Hay, Barnett, & Keating, 2000). In our previous VSS courses, undergraduate students have used 3-D modeling software to construct virtual reality models of the Solar System. The VSS course design is consistent with the principles of participatory learning environments (Barab & Hay, 2001). That is, we leverage computer-modeling technologies to create a learning environment that supports students in participating in collaborative problem solving through designing and building models that embody complex astronomical concepts.

This study reports on a pilot VSS curriculum module taught during the Spring 2000 at a small, rural Midwestern elementary school in which there were twelve fifth-grade participants. The VSS module was designed to be a two to three week project so that it could be embedded within, and support, a teacher's existing science curriculum. The goal of this project was to engage students in constructing a 3-D model of the Earth-Moon-Sun system. To this end, students were expected to investigate the orbital paths, periods, distances between, rotational rates, and the relationships between the Earth, Moon and Sun. The students were also asked to compare their model with the real Earth-Moon-Sun system and report on any discrepancies between the two. The project concluded with students posting their projects to WWW and presenting their model to the class.

Project: Motion of the Moon and Earth and Phases of the Moon: During this project students worked in teams of three to four to research the orbital motions of the Moon and Earth and to better understand how that motion influences the phases of the Moon. The focus of this project was on the students researching and gathering information about the orbital motions of both the Earth and Moon while trying to understand the position of the Moon in relation to the Earth and Sun during its different phases. At the beginning of this project, the students were provided with a few questions to scaffold their exploration; such as, "Where is the Moon relative to the Earth and Sun when it is in its new phase?", and "Where is the Moon when a solar eclipse is occurring?" The students researched these questions and tried to develop questions of their own, as they constructed their 3-D model. At the end of this project the students gave a brief presentation describing their model.

STUDY METHODS

Lincoln and Guba (1986) recommended triangulation as one means of increasing the credibility of researcher interpretations. To this end, data were collected through multiple sources, including videotaping of student classroom activity, pre and post interviews, semi open-ended pre-post questionnaires, and student created inscriptions and artifacts. Data analyses consisted of several stages. First, a detailed summary of each videotape was prepared. These summaries focused on how group conversations and teacher supports and feedback influenced student model building as well as the role of the technology in student model design and student learning. Second, case studies were created for each student team using a combination of videotaped observations, artifacts, and interviews. For the purposes of this manuscript we focus on a single case in which we examine the challenges and successes of the group and how engagement in their model construction process contributed to their success and failures.

RESULTS

The Case of Zach, Jeremy and Jance, the Stargazers

During the first day of the project the students were introduced to the modeling software and the resources that were available to them, such as books and numerous WWW sites. During the remainder of the day the students were guided through the navigation and use of the VRML software package. The students were introduced to the steps required in the process of making spheres, making them spin, and how to move one's perspective around in this 3-D space. After this introduction the students were given time to play and explore with the software package making spheres and animating them. At the end of this day each student group took five minutes to decide on their team name. Zach, Jeremy and Jance chose to call their group Stargazers.

At the start of the 2nd day the students were shown how to add texture maps to their objects. That is, they were shown how to make their sphere look like the Earth by wrapping a Mercatur map around the sphere. The students found this to be quite exciting and practiced this process for the next 10 minutes. The project then resumed with a guiding question prompting the students think about what they knew about the Earth, Sun and Moon. They were then asked to formulate a question that they would like to answer through their experiences building models of the Sun, Moon, and Earth. When asked by the instructor on the first day of the project what they knew about the Earth, Sun and Moon the Stargazers stated that the Sun was bigger than the

Moon, but they could not elaborate on their statement. Their initial question was to learn how much bigger the Earth is than the Moon.

When Zach, Jeremy and Jance began the modeling project, they simply began by making a sphere and changing its size and color. However, after a few minutes of learning how to manipulate the virtual reality modeling-objects, the students created a sphere representing the ***Earth. They were at a stopping point until the instructor came over and asked the students how they were doing.

Instructor:	So what is going on?
Zach:	What should we do now?
Instructor:	Well, you have an Earth? But is your Earth right?
Instructor:	Is the Earth up and down like that? Or is it tilted a little?
Jance:	Oh, it is tilted a little!
Instructor:	Do you know how much?
Jance:	No.

From this interaction we see that the students had not thought about the fact that the Earth was tilted on its axis. However, the instructor helped to guide the students to think about the accuracy of their model and the students did indeed include the tilt of the Earth. This interaction demonstrates that if young students are not given appropriate scaffolding or guidance while constructing their models, they may not realize that their model is incorrect.

The instructor then points the Stargazers to a book and tells them to see what they can find out about the tilt of the Earth. The students dig into the book and locate the angle at which the Earth tilts, 23.5 degrees. However, they are not sure which *way* it is tilted:

Zach:	So how do we tilt it?
Jeremy:	I'm not sure, maybe we tilt it like this (holds his hand up and tilts in a bit).
Zach:	Ok.

After a brief conversation, the Stargazers successfully tilt the Earth the appropriate number of degrees in their model. This was the first step in the model construction process for these students, with the rest of the construction process reflecting this initiation, conflict, conversation, and resolution pattern. That is, by constructing their model piece by piece the students could examine the different attributes of the Earth-Moon-Sun-system in isolation from one another to develop an understanding of those individual parts and problems associated with them. In the following interaction the students begin a critical examination of the question, "How big do we make the Sun?"

Zach: Ok, lets put in a Sun!
Jeremy: Where at?
Jance: Lets put it over there. (pointing to a place on the screen to the left of the Earth)

The students move on with their inquiry and make a Sun. This process takes them about 10 minutes, as they are on and off task during this time. In the process of constructing their Sun, the Stargazers do not concern themselves with the scaling factor of their model. Instead, they simply make their Sun bigger than the Earth. That is, rather examining how much larger the Sun is than the Earth in the real-world, these students simply construct a Sun that appears to be roughly the correct size. In fact, the students, at the time, appeared to be quite pleased with their model until the instructor came over and questioned them about their model.

Instructor: So tell me about your model so far?
Zach: Well, we put a Sun in now and we put the Earth right there (points to the Earth).
Instructor: How big is your Earth?
Zach: Clicking on the Earth to figure out how big it is. It is 10 meters.
Instructor: How big is your Sun
Zach: I don't know, it is bigger than the Earth.
Instructor: Ok, but how much bigger?

The next day the Stargazers continue to work with their model, this time with the intent of making it more accurate. They begin by looking up how much bigger the Sun is than the Earth in one of their textbooks. They discover that the Sun is 100 times larger than the Earth. However, they are not sure how to incorporate the information into their model. The students are stymied for some time and generally just talk about the "end of year water party" until the instructor comes over and asks how it is going.

Instructor: So what did you find out about the Sun?
Zach: It is 100 times larger than the Earth.
Instructor: Ok, so how big should Sun be in your model?
The group: Don't know (visibly frustrated at the question)
Instructor: Ok, so how big is your Earth in your model?
Zach: It is 10 meters.
Instructor: Ok, remember that number. Now how much bigger is the Sun as compared to the Earth?
Jance: 100

Instructor:	Ok, write that down. So if the Earth is 10 and the Sun is 100 times bigger than the Earth, how big will the Sun need to be in your model?
Zach:	Oh, 10 times 100.
Instructor:	Ok what is that?
Jance:	1000?
Instructor:	Good job, there you go.

This was the first time the Students had to worry about scale in their model. With this, we see that the students model has now taken a step up in complexity, as did their conversation. For instance, in this interaction the students had to concern themselves with the relationship in size between the Earth and the Sun, rather than just the size of the Sun itself. In fact, this model building conversation continued its extension when the students decided that they needed to put the Moon in their model:

Jeremy:	Ok, I want to put in the Moon. (Zach hands over the mouse to Jeremy).
Jance:	Ok, I guess the first thing is "How big is the Moon?"
Zach:	It is smaller than the Earth (laughing).
Jance:	I know that! How much smaller.
Zach:	Bet it is in that book.

The students again do a bit of research to find the size of the Earth, and eventually find out that the Moon is one-fourth the size of the Earth. However, the students are still at a loss concerning how to incorporate that knowledge into their model.

Zach:	Ok, so how big do you think we make it?
Jance:	Probably, how we did the Sun. The Earth is 10, so what is one-fourth of 10?
Jeremy:	I don't know (using their calculators the students determine that the Moon should be 2.5 meters in their model).

In this interaction, we see for the first time the students beginning to refer to their previous modeling experiences. Specifically, the students realized that they needed to be concerned with how large they made their other objects in the model and make the Moon the correct size in relation to their Earth and Sun. The students in this interaction have increased the level of complexity in their model, as well as in their thinking. That is, rather than simply worrying about the size relationship between two objects, they had to concern themselves with understanding the size relationship between three objects.

At this point in the project the Stargazers were ready to rotate their Earth around its axis. To assist the students in completing the task the first the time, the instructor led the students through the process of rotating their Earth. Based on his prior experience in constructing these models, the instructor suggested that the group make the Earth rotate once on its axis every ten seconds. After the students learned how to animate Earth, they excitedly moved on to animate their Moon so it would revolve around the Earth in their model. During this time, there were some technical problems in completing the animation. However, once solved, the students and the instructor examined their newly revised model with the following questions.

Instructor: Ok, so tell me about what you seeing?
Zach: What do you want to do know? The Moon is going around the Earth…
Instructor: Tell me about how often an eclipse occurs? Zach looks to Jeremy for help and Jeremy speaks up.
Jeremy: Well, [laughing]. I think there is an eclipse here [points to when the Moon is behind the Earth].
Instructor: Is that the only place? Can you tell me what an eclipse is?
Zach: It is when the Moon is made all dark.
Instructor: And what causes that?
Jance: Oh, Oh! I know, it is when the Earth is the Sun's shadow.
Jeremy: The Sun has a shadow? [laughing]
Jance: Oh, no the Earth has a shadow [laughing as well now].
Instructor: Ok, why don't you look up what an eclipse is and then try to figure out where there are eclipses in your model. [The instructor points out two books that explains where they find information about eclipses and the students dig in].

After about five minutes the students start talking again [a little pushing and elbowing as well] and begin to look at their model. By this point the students are very comfortable going back and forth between the modeling tool and the WWW browser to examine their model in motion. However, in examining their model the students begin to notice that their model seems to predict an inordinate number of eclipses.

Instructor: So what did you figure out?
Zach: We got it.
Instructor: Ok, tell me about your model then?
Zach: Well, we got the Earth there, and the Moon going around the Earth.
Instructor: Ok, tell me about your eclipses.
Zach: Well, we get them there and there [pointing to the screen, specifically when the Moon is behind the Earth and between the Earth and the Sun].

Instructor: Ok, so lets carefully run your model [tells them how to open their browser and watch their model].
Instructor: Ok, so point out your eclipses to me again?
Jance: There was one [the Moon passed in front of the Sun].
Instructor: Ok
Jance: There is another one [pointing out when the Moon is behind the Earth].
Instructor: Ok, so lets keep watching. I want you to count the number of eclipses you see.

The students begin watching their model and they notice that there model has eclipses much frequently than they had expected.

Instructor: Is anything wrong?
Zach: I don't think we should be getting eclipses that often.
Instructor: Why?
Jance: Well, we don't see them that much. So what is wrong? Zach must have done something to the model [laughing].
Instructor: Ok, you should do a bit of research and find out what is wrong with your model?

The students begin to read about the orbital tilt of the Moon in a book that the instructor pointed out to them. The students find that they have not accounted for the orbital tilt of the moon in their model. What follows is the conversation they have with each other about the book and their model.

Zach: Ok, hey! Look, it shows here that the Moon is doing this (draws in the air that the Moon is moving around the Earth at a odd tilt).
Jance: We didn't do that. Ours just does this (moves his hands around each other in the same plane)
Zach: Ok, so we need to make our Moon move like this (Tracing the projected path of the Moon on their computer screen).

This class ends before the students have time to finish revising their model. They return early the next day and quickly begin where they left off revising the Moon's representation in their model. The students go through the process of animating their Moon with the 5 degree tilt. After they are finished, they watch their model to see what happens.

Zach: Ok, lets hope this works (starting to run their model).

All: [Watching their model. The Moon is now orbiting the Earth at the 5 degree tilt.]
Zach: Ok, here it goes (getting near an lunar eclipse). Good didn't get one, so it must be right.
Jeremy: There it goes around. Will we get a solar eclipse?
Zach: I don't know. I don't think so. We shouldn't get very many I think?

Zach raises his hand to get the instructors attention. However, the instructor is busy with another group and Zach gives up and starts to look at his group's model again.

Zach: Watch (making Jeremy and Jance watch their model). We don't ever get an eclipse the Moon is always up here or down there (points that the Moon is either well above the Earth's orbital plane or well below).
Jance: We haven't watched for that long, maybe we will.

In this interaction we see the students are struggling to understand when and how often eclipses occur. However, the nature of the students' conversation has changed in that they are asking more questions of their model, not about their model. Their model has now grown complex enough that they can use it to begin to explore their understanding of astronomy. Specifically, the students are focusing on the orbit of the Moon and how the Moon's orbit affects when eclipses occur. Hence, the students are using their model as a tool to learn about astronomy and test their own ideas.

By this time, the students' model had evolved into a fairly complex system with the Moon orbiting the Earth and the Earth spinning on its axis. However, the Stargazers still struggled to make sense of their model with regards to how often eclipses occur. Furthermore, the students had yet to examine the phases of the Moon and the relationship between the phase of the Moon and its relative position to the Earth and the Sun. ***However, using certain features of the software package, the students could place viewpoints in their model and then examine their model from different perspectives. A viewpoint allows the viewer to experience the model from various perspectives and locations. For example, if a viewpoint is placed on the Moon focused on the Earth one would be able to observe the Earth from the perspective of the Moon. Adding viewpoints was the next step for group Stargazer.

Initially the instructor guides the students through the construction of a viewpoint, this takes about ten minutes and the students are told to practice placing viewpoints elsewhere. They practice placing viewpoints into their model, until they have about 50 different viewpoints. However, not all of the inserted viewpoints are valuable for meaningfully exploring their model. The students are instructed to clear all of their practice viewpoints and then told to think about where they would think a valuable perspective would be if the wanted to show someone what the phases of the Moon looked like or to explain a lunar eclipse. To guide the students during this process, they were given the following questions by the instructor:

1. Are the phases of the Moon the same if you are standing if Australia or Canada?
2. Does the Earth have phases when standing on the Moon?

The students then systematically go about placing viewpoints in their model. However, this time they argue and discuss concerning where to put their viewpoints.

Zach: Ok, so lets put a viewpoint on the Earth?
Jance: Put one in Australia
Jeremy: Put one in Indiana.

The students successfully place their viewpoints on the Earth and continue to place additional viewpoints on the Moon and elsewhere around the Earth-Moon-Sun system.

Jance: Lets put one on the Moon.
Zach: Which way should it be looking?
Jance: Looking at the Earth.
Zach: Ok, anywhere else?
Jeremy: How putting one up here, you know looking down.
Zach: Why?
Jeremy: That way we can see the Moon go around the Earth.
Zach: Good, ok.
Jeremy: What if we put one on the Sun.
Jance: Won't it be hot? (laughing)
Zach: It is only a model!

From the dialogue above, we see that the students are not critically examining why they are placing viewpoints. That is, the students are not engaging in the conversations about what information the different viewpoints are going to give them in terms of the Earth-Moon-Sun system. However, as they run their model, they begin to develop a better understanding of the system and why they must be more careful in evaluating where to place their viewpoints.

Jance: (running their model), ok what do we want to do?

Jeremy:	Lets go to the Moon!
Jance:	Ok (changes his viewpoint to be on the Moon).
Zach:	Woah! Look at the Earth?
Jeremy:	Hey! It has phases, Look it is getting dark.
Zach:	Yea, I bet if we wait it will be bright again, just like the Moon
Jeremy:	What if we had a camera on the other side of the Moon?
Zach:	I don't know lets put one.

Here we see the students have moved from simply building their model to using their model to extend their understanding of the Earth-Moon-Sun system. In particular, the computer software package allows the students to examine the Earth-Moon-Sun system from multiple perspectives. This ability to change perspective allows the students to dramatically increase the complexity, yet they can simply focus on a certain aspect, of their model's functionality. For instance, in the interaction above the students simply focused on what the Earth-Moon-Sun system looked like from the Moon.

DISCUSSION (more needed)

The case of the Stargazers demonstrated that the students' reasoning gradually became more model-based and less dominated by instances of experience. That is, in constructing models, the students engage in a process where their understanding of astronomy is distributed across their model, a graphical inscription, which becomes a tool to examine, and is apart of, their understanding of astronomical events. For example, our interviews suggest that when students first begin the construction of a model, they typically have their own mental model of what the final product should look like. However, by gathering information from their textbook, engaging in discussions with their peers, and leveraging interactions with the instructor, the students develop new shared meanings.

These shared meanings can then be examined and tested by using the tools available to their peers, in this case 3-D modeling software. These experiences facilitate discourse, question-posing, and hypothesis formation, by allowing students to construct and manipulate visual representations of their shared understandings that all of their peers can access. It is important to note that this visual representation and the accompanying discourse is not static, but fluid and open to question as each student brings to bear their individual knowledge and attempts to integrate it with the shared understanding embedded in their current construction. As additional information is reconstituted and coupled with the affordances of the modeling software (placing of viewpoints in this case), the model undergoes refinement through which its fluid properties, and in the process students' understanding, are continually being transformed into coherent descriptions of the natural world.

IMPLICATIONS

That is, the students develop mental models, and therefore instruction should be structured so that students can construct models that instantiate their own mental models so they can better reflect on and articulate their understanding.

Using 3D modeling software in an elementary classroom presents a unique combination of benefits and challenges. This type of learning environment provides students with meaningful opportunities in which they can engage in scientific inquiry. Clearly, these students were able to begin to develop the type of thinking necessary to use models not only as entities that are simplified representations of the real-world, but as tools that allow them to test new ideas by asking questions of their model. At the same time, both the technology and the mental visualization of these concepts can be challenging for students of this age. The instructor played a pivotal role in this classroom in terms of scaffolding the students through the process and providing them with guiding questions and assistance when needed.

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