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RESEARCH REPORT

Addressing children's alternative frameworks of the Moon's phases and eclipses

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In this study we conducted an analysis of a project based, space science curriculum designed to support elementary school students in understanding complex, inter-related astronomy concepts. The curriculum, rather than directly addressing students' alternative frameworks, focused on supporting students in identifying their own existing understanding and reflecting on how their understanding evolves over time. To assess student conceptual change, we conducted pre and post interviews, examined student work, and had students complete a pre- and post-astronomy conceptual survey. Our results suggest that elementary school students can develop sophisticated understandings of astronomy concepts. In addition, our results also suggest that the direct engagement of students' alternative frameworks may not be necessary if the students are immersed in learning activities that afford students opportunities to examine and reflect on their understanding. These findings point out the need that instruction respect students' pre-existing ideas and supports their reflection and discussion of their ideas.

Introduction

In this study we conducted an analysis of a space science curriculum designed to engage students in activities that support them in developing scientifically a sophisticated understanding of the relationship between the Moon's phases and eclipses. The intervention featured in this study was an eclectic instructional approach blending together class discussions, whole and small group activities, individual activities, and three-dimensional (3-D) dynamic computer models. These activities were designed to engage students in reflective thinking on and about their existing understandings. In the following sections we first present a summary of the literature, second provide a description of the instructional context, third give brief descriptions of the students that participated in this experimental course and our research methodology, and fourth, discuss the students' conceptual growth in relation to the astronomy concepts regarding the phases of the Moon and lunar and solar eclipses. We conclude with implications for the design of science instruction.

Background

According to the National Science Education Content Standards (National Research Council 1996) students in Grades 5–8 should have a clear notion about

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the direction of gravity when standing on the Earth, the shape of the Earth and relative sizes and distances between the Earth, Sun and Moon. However, several studies have shown that most students are far from such a robust understanding (Baxter 1989, Treagust and Smith 1989, Sneider and Ohadi 1998, Stahly *et al.* 1999). In fact, according to the Pfundt and Duit (1998) bibliography there have been over 116 studies reporting that students 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 *et al.* 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 *et al.* 1993).

During the past two decades there has been a growing interest in student understanding of scientific concepts and how their conceptions can be used to design instructional interventions (Driver and Oldham 1986, Baxter 1989, Vosniadou 1991). In analysing the results of these interventions, several researchers have concluded that these alternative frameworks are resistant to change. For example, a 1988 survey conducted by the Public Opinion Laboratory at Northern Illinois University determined that only 45% of United States adults could correctly state that the Earth orbited the Sun and that it took 1 year to complete the trip (as cited in Fraknoi 1996). Another dramatic example of the persistence of students' alternative frameworks can been seen in the film *A Private Universe* (Pyramid Film and Video 1988), in which Harvard graduates were found to hold several alternative frameworks about the cause of the seasons (i.e. the reason the Earth has seasons is primarily due to its changing distance from the Sun).

In response to these and other findings, educational researchers have focused on developing instructional strategies that directly address alternative frameworks during instruction. By directly addressing alternative frameworks researchers believe that students will be forced into a state of cognitive conflict and recognize the inadequacies of their prior understanding and replace their incorrect concept(s) with the correct scientific perspective(s) (Gilbert and Watts 1983). However, in recent years this replacement view of conceptual change has been challenged. That is, there is a growing body of literature which claims that instructional interventions designed to directly confront students' alternative frameworks may not be very successful in accomplishing conceptual change (Hewson and Hewson 1988, Muthukrisna *et al.* 1993, diSissa and Minstrell 1998). This research base suggests that conceptual understanding is an evolutionary process that emerges from a complex interplay between prior understanding and the context in which learning occurs (Smith *et al.* 1993). In this evolutionary view, students' alternative frameworks are a starting position to the construction of robust scientific understandings (Demastes *et al.* 1995). This process is facilitated when students are exposed to a curriculum that provides an experiential base in which students are afforded the opportunity to test and investigate their existing understanding through scientific discourse and meaningful activities (Muthukrishna *et al.* 1993, Penner *et al.* 1998). Therefore, from this perspective, instruction should focus on supporting students to participate in activities designed to foster student questioning and reflecting on their evolving understanding. Therefore, rather than designing instruction that characterizes student alternative frameworks as impediments to conceptual change, science instruction should use students' existing alternative frameworks to scaffold and provide opportunities for students to evaluate and reflect on their evolving understanding as they learn science (diSessa and Minstrell 1998)

Instructional context

Our instructional intervention was derived from two sources. The first source was the existing research on the teaching and learning of astronomical concepts (Sadler 1996). For example, Nussbaum and Novick (1985), and Vosniadou (1991) showed that students' understanding of gravity was closely tied to their understanding of the shape of the Earth. These studies suggest that the concepts of a spherical Earth, space, and gravity were closely connected. That is, students find it difficult to understand that gravity is directed toward the centre of the Earth if they do not understand that the Earth is spherical (Nussbaum and Sharoni-Dagan 1983). Further, if students are to develop an understanding of the reasons for the phases of the Moon, they first should understand the concept of how light reflects and that the Moon shines by reflecting light from the Sun (Vosniadou 1991). It has also been speculated that students may not be able to articulate understandings of the above astronomical phenomenon before they have a reasonable understanding of the relative size, motion, and distances between the Sun, the Moon, and the Earth (Treagust and Smith 1989, Vosniadou 1991). In other words, it is important for the teacher to consider what concepts are precursors for understanding more complex concepts rather than just selecting important astronomical concepts to teach (Ahlgren 1996).

The second source from which we derived our instructional intervention was the Challenger Center's existing space science curriculum (see http://www.challenger.org/). The Challenger Center's curriculum, which is used by nearly a quarter million students each year, consists of several inquiry and hands-on science activities ranging from constructing a scale model of the Solar System to examining the motion of the Moon and the Sun across the sky. By drawing from both sources we developed a curriculum consisting of scaffolding activities that guide the students from simpler concepts (the Earth is a sphere) to more complex and interrelated concepts (eclipses).

Instructional activities

We developed a set of projects consistent with the existing research that suggests that students need to understand certain astronomical concepts before progressing to more complex concepts (Ahlgren 1996, Sadler 1996). To this end, we sequenced the projects in the following manner: (1) the Earth as a sphere and gravity, (2) construct a scale model of the solar system, (3) light reflection and the cause of the Moon's phases, (4) the motion of the Earth and Moon, (5) the position of the Moon relative to the Earth during its different phases, and (6) the Moon's phases and lunar and solar eclipses. For the purposes of this manuscript we focus on projects 5 and 6.

Eclipses and phases instructional projects

The eclipses and phases portion of our instruction took 3 weeks (nine class periods) to complete and were the last four projects in our curriculum. In the first of these two projects, the students investigated the orbital motion of the Earth and the Moon and the spatial location of the Moon relative to the Earth as the Moon goes through its different phases. The second project involved students inquiring into the causes of lunar and solar eclipses and their relationship to the position of the Moon relative to the Earth. At the beginning of every project each student was asked to write down his or her initial beliefs about the Earth-Moon-Sun system in their learning journal (a notebook in which students keep a record of their ideas and how their ideas changed over time). Then, as a whole class, the students were asked to brainstorm and develop a list of facts and beliefs they had regarding the Earth-Moon-Sun system. At the conclusion of each class, the students were asked to compare and contrast their initial understanding about the Earth-Moon-Sun system with their post-class understanding either through their learning journal or through whole class discussions.

Project 1: motion of the Moon and the Earth and phases of the Moon. During the project students worked in teams of three to four to research the orbital motions of the Earth and the Moon and how their motion influences the phases of the Moon. In this project students researched and gathered information concerning the orbital motions of both the Earth and the Moon. While conducting their research the students were encouraged to develop ideas and hypotheses about how the position of the Moon relative to both the Earth and the Sun can determine the Moon's phase. In addition, this project required each student to make observations of the Moon's position and phase each night and to share and discuss their observations with their peers. To complement the students' real-world observations they also explored a 3-D interactive computer model (see figure 1) of the Earth-Moon-Sun system in which the students could view the Earth-Moon-Sun from different points in space (i.e. viewing the Earth from the Moon) and examine the shadows of the Earth and the Moon.

At the beginning of this project, the students were provided with a few guiding questions to scaffold their exploration such as, 'Where is the Moon relative to the Earth and the Sun when it is in its new phase?' and 'Where is the Moon when a solar eclipse is occurring?' The students research these questions and try to develop questions of their own using either the 3-D model or the other available resources with the teacher providing guidance and assistance when necessary (i.e. helping the students locate information or defining and explaining unfamiliar astronomical terms). The concluding activity of this project was a brief presentation in which the students described what they learned and how believed their understanding changed during the course of the project.

Project 2: eclipses and phases of the Moon. This project builds on the previous project as students conduct additional research into the relationship between the Moon's phases and lunar and solar eclipses. Like the first project, students work in small teams and use similar resources to conduct their research. A difficult concept for students to grasp is the difference between a full moon and a lunar eclipse. This difficulty arises from the fact that the Moon is 'behind' the Earth relative to the

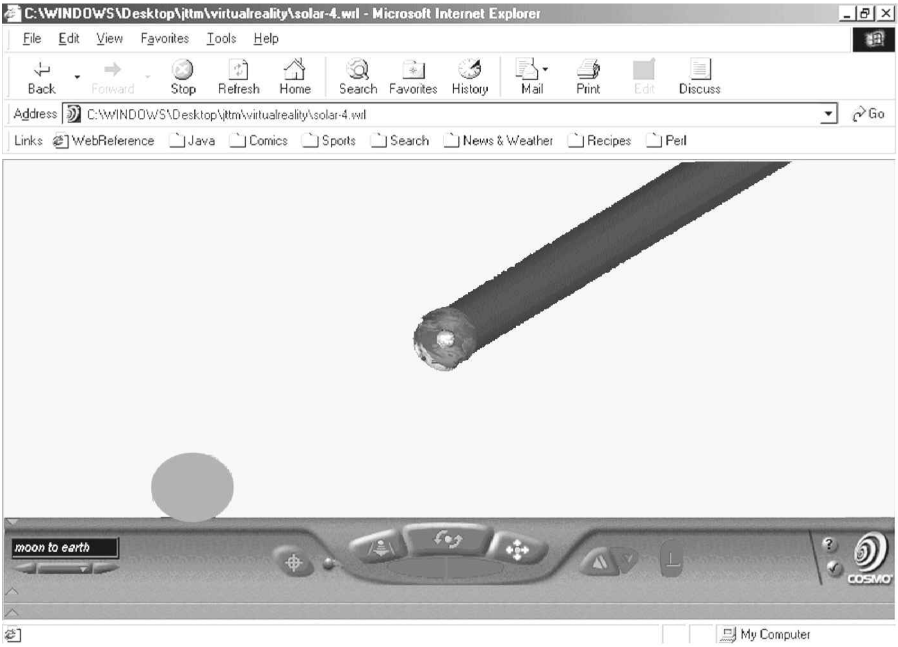

Figure 1. Screenshot of the computer model students used to investigate the phases of the Moon and eclipses.

Sun for both events. Therefore, the students were given initial questions that would support them in determining the differences between these two events (i.e. 'What does the shape of the Earth's shadow look like?'). Additionally, students made observations of the Moon noting the time, position in the sky, and phase of the Moon. Then using the data from their observations, coupled with the computer model and their research the students investigated the position of the Moon relative to the Earth during its different phases and during lunar and solar eclipses. At the conclusion of the project, the students were expected to describe how their understanding of the Moon's phases and eclipses changed from the beginning of the project.

This study

This study was conducted in a medium-sized rural elementary school during the fall term of 1999 over a 10-week period. The participants in this study were seventeen advanced Grade 5 students taking a special science course that met 3 days a week for the 10 weeks. The culminating activity of the course was to attend a local Challenger Center to simulate a NASA mission to the Moon in the year 2015. The goal of this mission was to determine the feasibility of developing a self-sustaining off-planet settlement. To successfully complete the mission the students needed to have to a rather sophisticated knowledge of the orbital motion of the Earth and Moon in order to navigate their spaceship from the Earth to the Moon. Further, the students needed to understand that the Earth casts a shadow and that when their ship enters the shadow it would be more difficult to navigate.

If the students were to avoid the Earth's shadow they first needed to understand the shape of the Earth's shadow so they could map a navigational path that avoided it. Participation in this project provided us with an opportunity to investigate the following two questions:

(1) Can students at the Grade 5 level develop scientifically sophisticated understandings of complex astronomical phenomena, namely the phases of the Moon and lunar and solar eclipses?
(2) Can students' alternative frameworks be ameliorated when exposed to instruction that does not directly address their existing alternative frameworks?

Lincoln and Guba (1986) recommended triangulation as one means of increasing the credibility of researcher interpretations. Data were triangulated through multiple sources, including direct observation, interviews, field notes, semi open-ended questionnaires, and student created inscriptions describing their understanding (see Appendix A). The 17 students that participated in the course were interviewed twice, once at the beginning of the course and once immediately following the completion of the course. However, only fourteen students completed both the pre and post interviews, and it is their data that we present in this manuscript. The interview questions (see Appendix B) were semi-structured, consisting of seven questions that covered a wide range of astronomy concepts with an emphasis on the concepts that relate to the Earth-Sun-Moon system. The questions were derived from the existing alternative conception literature and from our previous work (Sadler 1987, Treagust and Smith 1989, Sneider and Ohadi 1998, Barab *et al.* 2000, Barnett *et al.* 2000). In this manuscript, we focus on the following subset of interview questions with a particular emphasis placed on whether students could articulate the similarities and differences between the phases of the Moon and lunar and solar eclipses:

(1) Where is the Moon during the different phases (i.e., new moon, full moon...)?
(2) Can you tell me the positions of the Sun, the Earth, and the Moon for a solar eclipse?
(3) What are the differences between eclipses and phases of the Moon?

The pre-interviews were videotaped and conducted during the first two days of the course to determine students' conceptual understanding prior to instruction. The pre-interviews examined the ability of students to articulate and explain their understanding of astronomy and to identify the prevalence of alternative frameworks. The pre-interviews typically lasted 20–30 minutes. During the interviews the students were provided with a set of spheres for manipulation and paper for drawing to demonstrate and expand on their verbal explanations. The interviewer also asked probing questions to establish the depth of students' conceptual understanding. The post-interviews were also videotaped and conducted during the last week of the course. The post-interviews typically lasted 30–40 minutes. Again, the students were asked to express their understandings either verbally, as they manipulated spheres, or by drawing on the provided paper.

Table 1. Rubric for lunar and solar eclipses question.

(0) No conception: students are unable to articulate a response to the question.
(1) Confused: students confuse the positions of a full moon, new moon, and lunar eclipse. Students have one or more alternative frameworks. Students lack knowledge of basic concepts (Moon's orbital tilt, rotation and revolution rates) and proper terminology.
(2) Incomplete/Inaccurate Understanding: students have an alternative framework concerning either the positions of objects for eclipses and have hybridized their understanding with the correct scientific perspective. That is, in the students' explanation there are fragments of their prior understanding blended with aspects of the correct scientific perspective (i.e., a student explains that it is warmer during the summer in the northern hemisphere because the Earth is tilted toward the Sun and hence closer to the Sun). Students are also unable to articulate the difference between a full moon and a lunar eclipse and how the role the Earth plays in the occurrence of a lunar eclipse.
(3) Partial Understanding: students know the basic concept that an eclipse occurs when the Earth, Sun and Moon are lined up in a straight line. That is, students can point out the positions of a lunar eclipse and solar eclipse, but struggle to articulate the difference between a full moon and lunar eclipse. Students recognize the Earth's shadow plays a role in the occurrence of eclipses, but are unable to clarify their response.
(4) Complete Understanding: students understand that an eclipse occurs when the Moon falls into the Earth's shadow. The students also recognize that the Earth, Sun, and Moon have to be directly aligned in order for the either the Moon to be in the Earth's shadow or the Earth to be in the Moon's shadow. The students can point out the positions of a lunar eclipse and a solar eclipse, and can articulate the difference between the phases of the Moon and eclipses of the Moon.

Data analysis

We evaluated student conceptual understanding by extensive viewing of the videotapes, analysis and coding of the transcribed pre-post interviews, scoring the student responses by a rubric (see table 1), and by analysing the student responses to the open-ended questionnaires. The rubric is based upon the categorization scheme used by Barnett *et al.* (2000), where a score of 1 means the students were confused and tried to piece together their fragmented understandings into a coherent whole. A score of 4 represents a complete understanding of astronomical concepts. For the purposes of this paper we will concentrate on whether Grade 5 students can develop an understanding of the complex relationships between the Moon's phases and eclipses, and whether science instruction needs to directly address student alternative frameworks to promote conceptual change.

Results

Student conceptual growth

The similarities and differences between a full Moon and a lunar eclipse are difficult concepts for students to understand (Parker and Heywood 1998). Thus, we set out to develop a curriculum consisting of activities that would support students in developing a complete understanding of these complex astronomical concepts. When averaging, across students these activities seemed to facilitate conceptual growth as the students increased their average score from $M = 1.14$

Table 2. Student scores on eclipses and phases.

Student	*Pre score*	*Post score*	*Change*
Sally	0	2	2
John	2	3	1
Sue	0	2	2
Bob	1	3	2
Raphael	2	4	2
Jeff	2	4	2
Karen	2	3	1
Kate	0	2	2
Mary	1	3	2
Fred	0	2	2
Scott	1	3	2
Kurt	2	4	2
Kelly	2	4	2
Robin	1	2	1
Average	1.142857	2.928571	
	SD = 0.86	SD = 0.83	

(SD = 0.86) on the pre-test to M = 2.92 (SD = 0.83) on the post-test. ($\chi^2 = 15.4$, $p < 0.05$) (see table 2).

Pre-post interviews

In the pre-interviews the students could state what the different phases of the Moon were, but struggled to explain why the Moon had those different phases. In looking across students most held incomplete or confused understandings of the causes of the Moon's phases. On deeper probing, the students had difficulty in explaining the more complex relationships regarding the position of the Moon relative to the Earth as the Moon progressed through its different phases. In addition, the students also struggled to articulate the difference between the phases of the Moon and solar eclipses. The following excerpt from John's interview is quite representative of the students' reasoning:

Interviewer: Can you explain to me what causes the phases of the Moon?
John: We have a full Moon when, ah . . . when we can see all of the Moon. When, ah, um, the Moon is getting brighter it is called waxing, and when it is getting smaller it is called waning.
Interviewer: Ok, so where is the full Moon.
John: Hmm [laughing], that is an interesting question [laughs, and moves the spheres around each other].
Interviewer: Please feel free to tell me what you are thinking.
John: Ok, well, I think a full Moon will have to be back here [places the Moon sphere behind the Earth relative to the Sun], but I am not certain.
Interviewer: Ok, so where is a solar eclipse?
John: Ok, let me think [moving the spheres around]. The Sun is there [pointing to the ball that represents the Sun], and the Earth is here [in front of the Sun], so for a solar eclipse the Moon must be here [puts the Moon behind the Earth]
Interviewer: Why is the Moon there?
John: Well, because, well, the Earth can't see the light from the Sun?

Interviewer: Why not?
John: Because the Sun's light is being reflected away from the Earth by the Moon. I think, but I don't know.

Throughout the interview, it was evident that John had developed an understanding that consisted of conceptual fragments and struggled to blend these different fragments into a coherent whole. For example, he was able to state the different phases of the Moon, but had difficulty in explaining the location of the Moon during a solar eclipse. In addition, John had difficulty explaining the relative position of the Moon to the Earth when the Moon was full. Likewise, the pre-interviews revealed that six of the 14 students had similar fragmented understandings and hence were categorized as having incomplete understandings according to our rubric. The eight remaining students either could not articulate a response to the question or were confused in their response (see table 2).

These six students that had an incomplete understanding typically attributed the reasons for lunar eclipses to be due to the blocking of the Sun's light by the Earth, and the reasons for solar eclipses to the blocking of the Sun's light by the Moon. However, they were unable to articulate a description of the shape of the Earth's shadow or the role that the Earth's shadow played during the occurrence of a lunar eclipse. Hence, these students also experienced difficulties in blending their fragmented understandings into a form that allowed them to explain the relative positions of the Earth, the Moon, and the Sun during the Moon's full and new phases as demonstrated by Bob's pre-interview response below:

Interviewer: Could you show me where a full Moon is located?
Bob: I have no idea, but I will guess. [Holding the Moon sphere to the side of the Earth.] A full Moon would be when the Moon is between the Earth and Sun, it is shining on the full Moon, off to the side here the Sun is shining only on half.
Interviewer: Where would a new Moon be?
Bob: It would be over here. [Holds the Moon off to the other side of the Earth.] I think because the Sun can't hit it over here, but not sure?

Three students recognized that the Earth, the Moon and the Sun have to line up to produce a lunar eclipse, but they could not adequately explain why a lunar eclipse does not occur every month. They also had other alternative frameworks such as the Moon's phases being caused by the Earth's rotation as is demonstrated by Raphael's pre-interview responses:

Interviewer: So how do we get to see a full Moon from Chicago?
Raphael: I think it is because the Earth is spinning, and as the Earth spins we get to see different sides of the Moon.
Interviewer: So how do we get a lunar eclipse?
Raphael: I don't remember what a lunar eclipse is?
Interviewer: A lunar eclipse is when the moon becomes dark and bright again.
Raphael: Okay, we would need to get [the] Sun's ray's all blocked. As the moon circles behind the Earth, the Moon moves into the Earth's shadow. So the full Moon is when we can see all of the Moon and an eclipse is when the Moon is dark so we can't see it. I also think they have to be lined up exactly.

Several students also had difficulty in articulating the position of the Moon during a lunar eclipse and why we see the phases of the Moon. This is evidenced by

Karen's confusion with the cause of lunar eclipses and phases in the following sequence:

Interviewer:	When do we get a lunar eclipse?
Karen:	I think the Moon needs to be here [places the Moon sphere between the Earth and the Sun].
Interviewer:	Ok, why did you place it there?
Karen:	Well, because the Moon blocks the Sun's rays so we can't see the Moon.
Interviewer:	Ok, before you said that was where a new Moon is? So are lunar eclipses and new Moons the same?
Karen:	Um, I don't think so. I think it has to do with something on how the Earth spins and the shadow the Earth casts. I think it depends on how the shadow of the Earth hits the Moon. I am kind of guessing here, but I think that is how it [a lunar eclipse] happens.

During the interview it became clear that Karen already had developed a tentative mental model of the Earth-Moon-Sun system. However, Karen had not previously been asked to explain her personal model. That is, during the pre-interview Karen had to make her model public and through this process began to re-evaluate her thinking concerning when lunar eclipses occur. It was during these instances that the interviewing process provided the most valuable insights into how students construct and re-construct their understandings. For example, Karen began with a particular mental model but through reflection during the interview, tried to fit her existing understanding into a new and evolving model that bettered explained the phenomena being discussed.

The pre-interviews also revealed an interesting alternative conception concerning the spatial location of the Moon in its full phase held by three of the students. These students explained that the Moon needed to be located to the side of the Earth in order for the Moon to reflect the Sun's light back toward the Earth. This finding was consistent with students' understanding of the relative position of the Earth and the Moon during the Moon's different phases. Mary's pre-interview responses are similar in nature to Bob's and are representative of this line of reasoning:

Interviewer:	So where does the Moon have to be to get a full Moon?
Susan:	[Moving her spheres around] I'm not sure where it would be. Isn't that when the Earth can't cover any part of the reflection? I know it has do with the reflection of the light, and that we see all the near side, but I can't remember. When you see the shadow on the Moon isn't that the reflection of the shadow of the Earth? I don't know where it would be.
Interviewer:	Where would place the Moon sphere?
Susan:	Probably off to the side, so sunlight can hit it.
Interviewer:	So what does the Earth's shadow look like?
Susan:	It sort of looks like, well, I guess it just is dark and round behind the Earth.
Interviewer:	What would happen to the Moon if it passes into the Earth's shadow?
Susan:	I guess it would be hard to see. Maybe that is the new Moon then. Yes, that must be when a new Moon occurs.

Through the interview process it was evident that the students were constructing their understanding of the concepts *in situ* and that the interviewer's questions were catalysts that encouraged the students to re-evaluate their understanding. That is, during the interviews the students were wrestling with the complexity of the question and attempting to formulate responses that fit within their existing

Figure 2. Depiction of Karen's understanding of the shadow of the Earth.

conceptual framework. Therefore, interviewing students provided valuable insights concerning not only the mental models that students had developed to explain astronomical phenomena, but also revealed the thinking processes behind the formation of their personal constructions. The interviews also revealed that the students had fragmentary understandings, and during the interviews, the students attempted to meld these fragments into a larger conceptual structure that was consistent with each of their fragments and still explained the phenomena under discussion (i.e., what a full Moon is and the position of the Moon during a solar eclipse and when the Moon was full). For example, in Susan's pre-interview she believed that the phases of the Moon were caused by the shadow of the Earth. That is, she understood that the Earth casts a shadow and that the Moon goes through varying degrees of brightness and darkness, which results in the Moon's phases. Yet, when Susan was asked to draw what she thought the Earth's shadow looked like when the Moon was in its full phase, she drew a shadow extending away from the Earth but not quite extending to the Moon's location (see figure 2). In her drawing, the Earth's shadow doesn't reach the Moon so it cannot be responsible for the Moon's phase, which disagrees with her interview statements. Hence, similar to the other students, Susan had previously developed a mental model of the Earth-Moon-Sun system but had not had opportunities to reflect and evaluate her mental model and so was continuously amending and evolving her model to fit what she believed was a correct explanation.

Post-interviews

The post-interview results indicate that several students developed a solid understanding of the similarities and differences between eclipses and phases of the Moon. Five of the students developed a sound understanding, while four students developed a partial understanding. Whereas, five students still had an incomplete understanding at the conclusion of the course (see table 2).

Generally, students could articulate their understandings more concisely and understood causes of the Moon's phases and could explain the difference between an eclipse and full moon. That is, the students had moved from a set of unconnected and fragmented understandings to having a firmer grasp of how the different aspects of the Earth-Moon-Sun system fit together. This shift is demonstrated in John's statement:

> Interviewer: Now can you show me where the Moon is during a solar eclipse?
> John: A solar eclipse is where you cannot see the Sun. So you would have to put it right there [between the Earth and the Sun].

Interviewer: Why did you put the Moon there?
John: Because the Moon, Sun, and Earth have to be directly aligned to block the Sun's light from hitting the Earth.
Interviewer: Ok, so where is the Moon during a lunar eclipse?
John: A lunar eclipse is when we can't see the Moon. So it would be here [puts the Moon behind the Earth].
Interviewer: Why is the Moon there? Is that different from a full Moon?
John: The Moon is there because the Earth blocks the light from getting to the Moon, so we have a lunar eclipse. A full moon would have to be up here somewhere [holds the Moon above the Earth in view of the Sun]. Because if it was down here [lunar eclipse position], it would be [a] lunar eclipse. The Moon has to see the Sun for a full Moon.
Interviewer: Where would the Moon be for a new Moon?
John: It would be here between the Sun and the Earth.
Interviewer: Why is that different than a solar eclipse?
John: It is because they are aligned up exactly right. Because the Moon's shadow is hitting the Earth right here [points to the Earth]. Then as the Moon moves, the shadow will move, until the Moon is over here [away from the Sun] and then there will not be any more eclipse.

Hence, John developed a partial understanding of the relationships between the phases of the Moon. However, the spatial relationships between the Earth, the Moon, and the Sun and how their relationships affect eclipses continued to be difficult for John to understand. Further, John had difficulty in articulating the role that the Earth's and Moon's shadows play in lunar and solar eclipses. Hence John had amended his initial mental model of the Earth-Moon-Sun system to a more sophisticated model, which can provide a richer foundation upon which future instruction can continue to assist him in refining and evolving his understanding.

Despite the fact that several students developed complete or partial understandings, several students continued to have difficulties in developing conceptual understandings of the relationships between the Earth, the Moon, and the Sun. For example, five students developed incomplete understanding and hybridized understandings between their prior understandings and the scientific explanation they learned about during the instructional activities. For example, this set of five students had difficulty in determining the difference between a full Moon and lunar eclipse even if they understood the reasons for the phases of the Moon as demonstrated in Sally's response:

Interviewer: Can you tell me where a full Moon is going to be?
Sally: Probably going to be about right here, because it can get the sunlight. Not directly behind the Earth, just a little off to the side.
Interviewer: Where would a lunar eclipse be?
Sally: Maybe it would be back here. So the Sun would be hitting this [the Earth], and since the Moon is spinning, we would gradually see different parts of the Moon (orbits the Moon around the Earth).
Interviewer: Ok, so you held your moon here for a full moon and your moon there for a lunar eclipse. Why are they different?
Sally: Because, the full moon is caused by sunlight hitting the Moon and bouncing toward the Earth so we can see it.
Interviewer: So what about the lunar eclipse?
Sally: Oh, the Moon needs to be here [behind the Earth] because no light can get back here. It is all black back here so we can't see anything.
Interviewer: Ok, now where does a new moon have to be?
Sally: I think it is has to be here [behind the Earth] because the Moon can't get any light so it can't reflect any light toward the Earth.

Interviewer: So how are lunar eclipses and new moons different?
Sally: Well, one is when the Moon is in the Earth's shadow and the other is when the Moon can't bounce light back to the Earth.

Here we see that Sally has a developed a good grasp on the understanding of the causes of the phases of the Moon, why the Moon shines, and the position of the Moon during a lunar eclipse. However, when probed Sally had developed a hybridized understanding that the new Moon and lunar eclipses are both caused by the Earth's shadow because it prevents light from reaching the Moon. This result was not too surprising considering that when Sally was asked to draw a picture of the Earth's shadow, Sally clung to her alternative framework that the Earth's shadow encompasses everything behind it (see figure 3). That is, Sally attributed both the new Moon and lunar eclipse to the Moon being in the Earth's shadow.

However, four students developed a complete understanding of the complex relationships between the Earth-Moon-Sun system. These students had developed understandings that blended their previously unconnected notions and ideas concerning the Earth-Moon-Sun system. Kurt's following interview excerpt is representative of these students' reasoning:

Interviewer: Why is that position a new moon?
Kurt: Because the light is being bounced back to the Sun so we can't see the Moon.
Interviewer: Where would the Moon be for a solar eclipse?
Kurt: It would be here [pointing between the Sun and the Earth].
Interviewer: Why did you place the Moon there?
Kurt: Because the Moon, Earth and Sun need to perfectly lined up, and then the Moon is casting a shadow on the Earth? Like if this was China they would be seeing a solar eclipse.
Interviewer: Would you be seeing one in the USA?
Kurt: No, because the Moon has such a small shadow. Lunar eclipses are very vast they cover the entire night sky, they are much more frequent than a solar eclipse.
Interviewer: Why are they more frequent?
Kurt: Because the Earth's shadow is much bigger than the Earth. The Moon has very little shadow.
Interviewer: Ok, imagine you are standing on the Moon, and you are looking back at the Earth. Would you see phases of the Earth?
Kurt: Yes, you would. If you would be standing on the Moon you would see half, new, full moons. It would be just like the phases of the Moon.
Interviewer: Why does the Moon have phases?

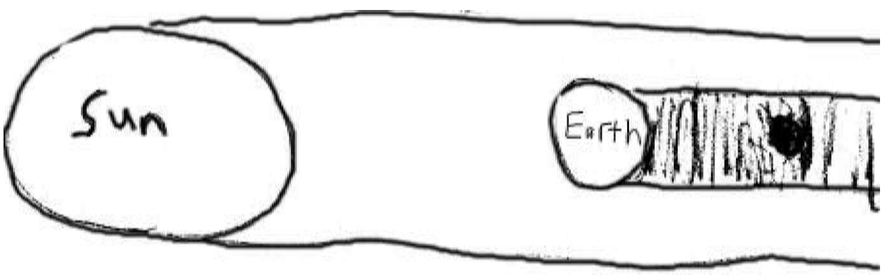

Figure 3. Sally's post project representation of the Earth's shadow. The circular dark region represents the Moon.

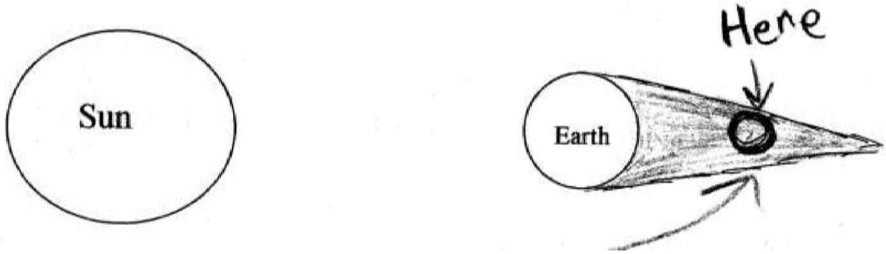

Figure 4. Kurt's post-instructional drawing of his understanding of the shadow of the Earth and the position of the Moon during a lunar eclipse.

Kurt: Because of the angle between the Earth and the Moon. We see the light that is reflected off the Moon and toward the Earth. So here we see a half moon because the Sun is lighting up this side of the Moon. But we can only see this part, but only this part is lit.

According to our rubric, Kurt was categorized as having a complete understanding. Kurt's interview also revealed that he was not only able to articulate the reason the Moon has phases, but also explain that the Earth has phases when viewed from the Moon. In addition, he could explain why there is a high likelihood of viewing a lunar eclipse than a solar eclipse from the Earth. Lastly, when asked to draw what he believed the Earth's shadow looks like and where the Moon is during a lunar eclipse, Kurt drew the Earth's shadow as a cone and placed the Moon within the shadow of the Earth (see figure 4).

In summary, the majority of students began the course with an incomplete or confused understanding of the causes of the Moon's phases and eclipses. Despite some student difficulty in articulating the differences between a full moon and lunar eclipses, the post-interviews revealed that the students did increase in their understanding. However, only nine of the students developed either a partial or complete understanding with the remaining students having an incomplete understanding. In addition, their initial explanations included a number of common alternative frameworks including explaining the difference between lunar eclipses and phases of the Moon as having to do with the Earth's rotation. However, by the end of the course all of the students had developed more robust understandings than they had prior to instruction, and only five of the students still clung to their prior alternative frameworks.

Student reflection opportunities: promoting conceptual change

There was evidence in student learning journals as well as in class reflections and discussions that students' understanding of astronomy concepts evolved as a result of their experiences in completing the curriculum activities. For example, John, who showed considerable conceptual movement in the pre-post interviews presented above, wrote in his journal prior to instruction:

> I know the phases of the Moon are caused by the sunlight hitting the Moon. I think that eclipses are when the Earth gets in the way of the Sun. Depending on how light hits the Earth we can see a solar eclipse or a lunar eclipse.

In John's next entry after studying the orbital motion of the Earth and the Moon and the shape of the Earth's shadow he wrote:

> Looking back, I was way off! It turns out that eclipses are caused by the Earth shadow. When the Moon is in the Earth shadow we see an eclipse! Cool!

However, not all students were as verbose as John in their writing and those students, like Bob below, discussed their understanding in whole class discussions:

Instructor:	Ok, what did you learn today about eclipses?
Bob:	[raising his hand] I learned that eclipses are caused by the Moon passing into the Earth's shadow.
Instructor:	What kind of eclipse is that?
Bob:	That is a lunar eclipse? Because we can see the Moon, 'cause no light can hit it when it is [in] the Earth's shadow.
Instructor:	Is that different from what you believed when you started today? That is a question for everyone, so everyone look back to what you wrote down about what you believed about eclipses before we started today? [a 12 minute of silence]
Instructor:	Ok, lets start with Bob. Do you believe anything any different now?
Bob:	I think so [laughing a little]. I did not know that a new Moon and a lunar eclipse were different. It depends on the shadow.
Instructor:	What shadow?
Bob:	The shadow of the Earth.
Instructor:	Great! Anyone else?
Sally:	I learned that the phases of the Moon and eclipses are about the same, but that the eclipses happen when the Sun, Earth, and Moon are directly lined up. Before I was not sure I thought anything, but I knew it had something to do with light.

In these whole classroom exchanges, the focus was on developing an environment in which students were open and comfortable in sharing their thoughts and ideas rather than engaging in content-related issues. Further, the instructor felt that Bob understood the content well (through his other written work and comments) and did not feel compelled to push Bob on his understanding. However, this does point out the necessity of having multiple means of assessing students' conceptual understanding because according to pre-post interviews Bob had a rather brittle understanding of the role the Earth's shadow plays in lunar eclipses.

Another student, Kurt, expressed that the content was hard to understand, but that he thought it was not only fun to learn but also reflected on his previous thinking as he was motivated to learn more as shown in his following statement:

> I thought understanding the phases of the Moon was hard, but understanding why eclipses occur was even harder. I didn't know about the Earth's shadow or the Moon's. I always thought eclipses were caused by, well, [I'm] not sure what caused them, but I thought it had something to do with clouds. These classes are cool and [I] would like to learn more about space.

Most students wrote in their journals or discussed their understanding with either their peers or the instructor. This reflection not only assisted students in keeping track of their understandings, but also provided a conduit through which students could develop an awareness of their existing understandings and how their understandings changed during the course.

Discussion

The majority of students began the course with particular understandings of various aspects of the Earth-Moon-Sun system. In general, all students had developed some sort of mental model of the Earth-Moon-Sun system that they used to explain natural phenomena such as the phases of the Moon and eclipses. However, these models typically consisted of disjointed and unconnected understandings of the relationships between different events and objects. For instance, prior to the instructional activities a number of students could explain the different phases of the Moon and had developed multiple reasons concerning why the Moon has phases. It was these prior student understandings that served as a foundation upon which they built their more sophisticated understanding as the course progressed. For example, rather than viewing the full moon and new moon as two separate phenomena, the students had developed an understanding that the new moon and full moon can be explained more simply by showing how the Moon orbits around the Earth and that the Moon shines by reflecting sunlight. That is, the instructional activities supported students in bringing together their already existing understandings in such a way that they could begin to view the larger system in which the Moon is simply a part. Hence, by the end of the course, a majority of students developed at least a partial conceptual understanding of eclipses and phases. The concept of the relative positions of the Earth, the Moon, and the Sun, in combination with the shadows cast by celestial objects (i.e., the Earth and the Moon), emerged as important conceptual tools to be mastered if students were to obtain a complete understanding of the differences and similarities between phases of the Moon and eclipses.

Conceptual change theory as posited by Posner *et al.* (1982), requires that students first be dissatisfied with their existing conceptual understanding before meaningful change will occur. By engaging students in activities that support reflection on their evolving understanding and by having to present their understanding to their peers (e.g., through class discussions) the students are affords students the opportunity to re-evaluate their understanding. This process is facilitated when students are provided meaningful activities that are related to their personal experiences. For example, when we asked our students the location of the Moon during its new phase, a typical student response involved placing the Moon on a straight line between the Earth and the Sun. However, when asked to describe how the position of the Moon for a new Moon is different than for a lunar eclipse, students become puzzled over the fact that the positions appear to be the same. They quickly realized that the two events cannot occur at the same position in space, and are forced to re-evaluate their understanding of the two phenomena and, through this process of reflection, re-evaluate their understanding of both phenomena.

In many elementary science courses students are not afforded the opportunity to reflect on their learning. This state of affairs is not because the average teacher does not value student comments, but they frequently have to satisfy certain curriculum requirements, and allowing students time to reflect on their understanding during class can be a time consuming task. Yet, by reflecting on their understanding students engage in conversations around and about their understanding and how their understanding evolves over time. That is, by articulating the evolution of their understanding students not only become aware of their previous conceptions, but also how those conceptions can and cannot explain particular scientific phenomena. Hence, conceptual change can be facilitated when time is taken to allow students to take note of their own understanding and reflect on that understanding.

Limitations

The findings in this study suggest that students at Grade 5 level can develop a sophisticated understanding of the phases of the Moon and eclipses and that instruction does not necessarily need to directly address students' alternative frameworks to promote conceptual change. However these findings need to be tempered somewhat. For instance, the post-interviews occurred immediately at the conclusion of the course whereas a delayed interview of perhaps 6 months to a year would yield more conclusive evidence that students' conceptual understanding did indeed change. In addition, the class size was small, and the students were taking the course by their own choice. Therefore our instructional techniques will need to be used with a larger group of students and within a more traditional science classroom if we are to make any generalizeable claims concerning student learning. A possible means of scaling this study to examine additional astronomy questions as well as a larger population of students could be the development of a multiple-choice exam focused on astronomical concepts coupled with random interviews. For example, a few conceptual multiple choice exams have been developed to assess student understanding (Sadler 1996, Schau *et al.* 1999), yet an improvement to these would be to have the students also justify and explain why they chose a particular response. Then by randomly interviewing a subset of students, researchers could develop insights into the nature of students' existing conceptions and how these conceptions change over time. Further, if the responses from such a multiple choice exam could be categorized and presented in a format that was easily accessible for a classroom teacher, the likelihood of that teacher being able to develop instructional activities that support student conceptual change based upon their existing understanding would be enhanced. Further, this study only focused on a small subset of astronomy questions and that an investigation with a larger set of questions could reveal a richer understanding of the various mental models that students develop and how they use those models to explain relationships between astronomical phenomena. Lastly, the pre-interviews could have impacted students' performance on the post interviews. For example, in this study we observed that during the pre-interviews the students began to re-evaluate their understandings during the pre-interview. In other words, the pre-interviews could have sparked some students' to think more critically about their understanding. Hence, one avenue for future research is to begin to untangle the role of pre-interviews from the curricular intervention through the performance of controlled studies in which one group is pre and post interviewed and another group is not pre-interviewed but exposed to the same curricular intervention. Despite these limitations, the findings presented here suggest that future research should be conducted to further examine whether student alternative frameworks need to be directly addressed during science instruction to promote conceptual change.

Implications

A large number of prior studies have reported that students have several alternative frameworks concerning astronomical phenomena (Baxter 1989, Finegold and Pundak 1990, Schoon 1993). These alternative frameworks are typically the products of prior student observations and experiences. Traditionally, science instruction has focused on instructional techniques designed to replace student alternative frameworks with that of more 'correct' frameworks (diSessa and Minstrell 1998). To this end, we developed an instructional intervention that featured a conceptually scaffolded curriculum based upon our pedagogical commitment that students learn best through projects that engage them in discussing, reflecting on, and articulating their evolving understandings. That is, when designing instruction curriculum developers and teachers should focus on supporting students in thinking about their ideas in relationship to their existing understanding and the ideas that they are trying to learn (Beeth 1998).

Developing instruction that directly addresses students' alternative frameworks requires that teachers be aware of their students' alternative frameworks, which is rarely the case (Sequeira *et al*. 1993). Further, to directly challenge all of their students' alternative frameworks requires a sizable amount of individualized attention per student, as each student has experienced different situations in which to develop their understandings (Voska and Heikkinen 2000). This individualized attention and management of each student's alternative frameworks frequently requires more instructional time than the average teacher can provide (Hawkins and Pea 1987). In closing, it seems natural that students will develop a more scientifically sophisticated understanding of natural phenomenal when instruction is designed to actively engage students in activities that afford them opportunities to not only become aware of their own understanding but also to reflect and discuss their understanding in an environment where discussion about ideas is valued.

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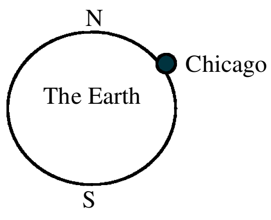
Appendix A

Semi-opened concept questionnaires

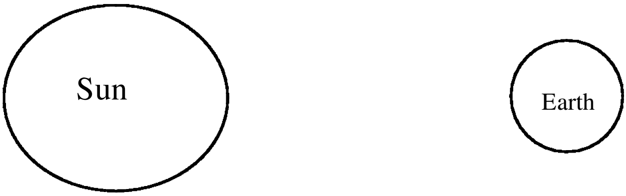
Please read each of the following statements and please answer the question as well as you can. Again, there is no right or wrong answer. Please answer each question as best you can.

(1) The below image represents the Earth. Please show the direction of gravity when you are standing on the North Pole, South Pole and in Chicago.



(2) Imagine that the Earth is the size below. Please draw how big you think the Moon would be relative to the Earth below.

(2a) How big do you think the Sun would be if the Earth is the size that it is in the above? Please explain why you believe the Sun would be that size.
(3) In the middle ages many people were scared of solar eclipses. People would hide in caves and even jump off cliffs because they thought the end of the world was coming. How would you explain to someone today what a solar eclipse is?
(4) Can you draw the positions of Moon when it is at full Moon, new Moon, and quarter Moon?
(5) In the below diagrams we have the Sun and the Earth. Can draw what the shadow of the Earth looks like?



(6) Please draw the Moon where you think it will be during a lunar eclipse in the above diagram? Why did you place the Moon there?

Appendix B

Interview questions

Gravity concepts

(1) What is the shape of the Earth and the Moon? Why does the Earth have day and night?
(2) Can you draw for me the motion of the Earth, Sun and Moon?
  (a) How long does the Earth take to go around the Sun?
(3) Imagine you are on the North Pole. Which way do you think gravity pulls on you? If you are on the South Pole which way does gravity pull you? If you are in Chicago which way does gravity pull on you? What if you are an astronaut in the space shuttle orbiting the Earth which way does gravity pull on you?

General space science/astronomy concepts

(4) Can you draw a scale model of the Earth, Sun and Moon?
(5) Can you tell me what causes the phases of the Moon?
(6) Can you show me the position of the Sun, Earth and Moon for a lunar eclipse to occur?
  (a) How about a solar eclipse?
  (b) Why do you think eclipses are so rare?
  (c) What is the difference between a lunar eclipse and a new moon?
  (d) What is the difference between a solar eclipse and a full Moon?
(7) Imagine you are standing on the Moon, do you think the Earth will have phases? If so what do you think they will look like?