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A Longitudinal Study of Conceptual Change: Preservice Elementary Teachers' Conceptions of Moon Phases

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Abstract: This research consists of a longitudinal study of 12 female elementary preservice teachers' conceptual understanding over the course of several months. The context in which the participants received instruction was in an inquiry-based physics course, and the targeted science content was the cause of moon phases. Qualitative research methods, including observations and interviews, were used to investigate and describe participants' conceptual understanding over time. Participants were interviewed on their understanding of the cause of moon phases before instruction, 3 weeks after instruction, and again in delayed post-interviews several months after instruction. Patterns and themes in the participants' conceptual understanding were identified through constant-comparative data analysis. Consistent with results reported earlier, participants who had instruction that included recording and analyzing moon observations over time and psychomotor modeling of changes in moon phases were very likely to hold a scientific conceptual understanding shortly after instruction. The present study indicates a majority of participants continued to hold a scientific understanding six months or more after instruction. However, some participants reverted to alternative conceptions they had shown during the pre-interview. These results are interpreted utilizing contemporary conceptual change theory. © 2006 Wiley Periodicals, Inc. J Res Sci Teach 44: 303–326, 2007

Children may enter elementary school with substantial knowledge constructions, or explanatory conceptual frameworks, about the physical world (Vosniadou, 1999). Further, children's knowledge constructions frequently are at odds with scientifically accepted norms (Champagne & Klopfer, 1983; Driver & Easley, 1978; Driver & Oldham, 1986; Erickson, 1979; Osborne & Freyberg, 1985; Palmer, 2001; Pfundt & Duit, 1991; Strommen, 1995; Trend, 2001).

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Conceptual limitations that adults exhibit, including teachers, often are very much like those documented in children (Lewis & Linn, 1994; Trundle, 2003; Trundle et al., 2002, 2004). It follows that a strong need exists for instruction that is effective in helping students and teachers construct a scientific understanding of many fundamental science concepts (Carey, 1985; Duschl, 1990; Dykstra, Boyle, & Monarch, 1992; Gunstone, Gray, & Searle, 1992; Hewson, 1981; Schnotz, Vosniadou, & Carretero, 1999; Tyson, Venville, Harrison, & Treagust, 1997; Vosniadou, 1994).

Because nonscientific, or alternative, conceptions that students bring to a variety of instructional settings are frequently internally coherent and robust (Vosniadou, 1999), it is not surprising they are persistent and difficult to change. Further, conceptual change that does result from science instruction may differ from intended effects (Arnaudin & Mintzes, 1985; Hewson, 1981; Hewson & Hewson, 1983; Nussbaum & Novak, 1982; Stepans, Beiswenger, & Dyche, 1986; Vosniadou, 1999).

The present study draws from foundational conceptual change literature in science education (Beeth, 1998a, 1998b, 1998c; Driver & Oldham, 1986; Hewson & Hewson, 1983, 1988; Posner, Strike, Hewson, & Gertzog; 1982; Strike & Posner, 1985, 1992) and more heavily on recent literature that reflects a conceptual development perspective (Carey, 1985; Vosniadou, 1991, 1994, 1999, 2002, 2003; Vosniadou & Brewer, 1994; Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001; Vosniadou, Skopeliti, & Ikospentaki, 2004). Vosniadou's conceptual change views, which have been informed by several studies involving earth and astronomy concepts, appear to be particularly useful when thinking about conceptual change in science education. The following perspectives on conceptual understanding and conceptual change ideas, which guided our work, draw heavily on the conceptual development perspective articulated by Vosniadou. These include:

1. Preconceptions may form prior to formalized instruction.
2. Preconceptions can be organized, coherent, and highly resistant to change. These initial conceptual structures, which are often at odds with scientifically accepted norms, may facilitate or hinder learning.
3. Conceptual change may be time-intensive and gradual, occurring with experiences over extended periods of time.
4. Conceptual change involves more than cognitive aspects and may be influenced by beliefs, motivation, learning attitudes, and sociocultural contexts.
5. For some science concepts, the frequency with which specific alternative conceptions are held is consistent across diverse populations (i.e., age, abilities, nationalities).

These perspectives provide the theoretical framework for this study.

Previous conceptual understanding research in science education primarily has consisted of descriptive studies, which identified commonly held alternative conceptions. Although documenting commonly held alternative conceptions across diverse populations is an essential first step, the generation of this knowledge alone is insufficient. Smith, diSessa, and Rochelle (1993) encouraged researchers to "move beyond the identification of misconceptions" and to focus on "detailed descriptions of the evolution of knowledge systems over much longer durations than has been typical of recent detailed studies" (p. 154). Georghiades (2000) suggested researchers should focus more attention to the durability of a desirable conceptual change. The present study intends to address these needs.

Targeted Science Content

Researchers have studied conceptual understanding, including alternative conceptions, of moon phases for more than 70 years (Cohen & Kagan, 1979; Jones & Lynch, 1987; Treagust, 1988). Consistent with alternative conception research generally, the majority of moon-phase research published thus far has been descriptive (Baxter, 1989; Bisard, Aron, Francek, & Nelson, 1994; Dai & Capie, 1990; Haupt, 1950; Kuethe, 1963; Schoon, 1992, 1995), and has seldom included a study of conceptual understanding after an instructional intervention. The results of the descriptive studies before an instructional intervention indicate that most people, including preservice teachers, do not have a scientific understanding of the cause of moon phases.

A review of the literature revealed six studies that did focus on instructional effects for students' understanding of moon phases (Callison & Wright, 1993; Sadler, 1987; Stahly, Krockover, & Shepardson, 1999; Targan, 1988; Trundle et al., 2002; Zeilik, Schau, & Mattern, 1999). In all of these studies, post-assessments were administered shortly after the completion of instruction. Trundle et al. (2002), with the longest delay, gathered data 3 weeks after completion of instruction. Callison and Wright (1993) administered post-assessments immediately after instruction and then again after a 13-day interval. In the other studies post-testing was completed immediately after conclusion of instruction (Stahly et al., 1999; Targan, 1988; Zeilik et al., 1999).

Purpose of Study

Science instruction associated with conceptual change is demanding and time-consuming. Therefore, the question of how desirable changes in conceptual understanding documented immediately after instruction persist or change months after instruction is particularly important (Georghiades, 2000). For moon phases, as well as for other topics, there could be a lag of many months between the time preservice elementary teachers receive instruction in teacher preparation programs and when they instruct children. It is assumed that a teacher's conceptual understanding is one of several factors influencing instructional effectiveness. In pursuing the durability issue, the following research question was addressed: How does the conceptual understanding of preservice elementary teachers on the cause of moon phases change from pre-instruction to post- to delayed post-interviews conducted 6 or more months after instruction?

The research reported here is an important extension of an earlier study (Trundle et al, 2002), which examined the effectiveness of an instructional intervention for 63 preservice teacher participants. The earlier study also compared the instructional effects of pre-instruction interviews using two-dimensional (2D) drawings and three-dimensional (3D) analogical models. The present study is an in-depth analysis of 12 women's conceptual understanding of moon phases, before, immediately following, and months after instruction.

Methodology

Instructional Context

More than a decade ago, Vosniadou (1991) identified three critical characteristics of instruction aimed at restructuring entrenched nonscientific conceptions with a scientific explanatory conceptual framework. These characteristics, plus a fourth, which reflects a contemporary addition (Vosniadou, 2003), are described in what follows. The instruction:

1. Creates conditions in which students evaluate empirical evidence that is contrary to their beliefs.
2. Provides clear explanations of scientific concepts, preferably through conceptual models or analogies.

3. Utilizes demonstrations that show how the scientific models and explanations are superior to nonscientific conceptions and explanatory frameworks.
4. Promotes intentional learning, which is viewed by the learner as being purposeful and is characterized by a high level of metacognitive awareness and self-regulation.

The instruction provided to the participants in this study was planned to reflect these characteristics.

Because the instruction was fully described in an earlier study (Trundle et al., 2002), only a brief synopsis is included here in order to connect it to the four characteristics of instruction to promote conceptual change. Participants received instruction on moon phases while enrolled in a physics course specifically designed for preservice elementary teachers. The class met 2 hours on each of 3 days per week for a semester. After 9 weeks of making and recording data associated with direct observations of the moon, including drawing observed shapes of the moon, the small groups of teachers engaged in analyses of their data. Attention was focused on observed shapes, recurring patterns of change in observed shapes, and a pattern of change in the moon–earth–sun angles. Consistent with instructional characteristic #1 just given, it was noted that shapes only associated with a partial eclipse were absent from the students' data. The psychomotor modeling of moon–earth–sun relationships that followed was also consistent with characteristic #1 in that the moon model had to be revolved around the earth model to simulate the shapes and angles that had been obtained empirically. Further, students determined the moon, earth, and sun could not be in the same plane in order to simulate the moon shapes and patterns of change in shapes they had observed. Consistent with characteristic #2, the students and the instructor worked together to identify four critical elements in a scientific explanation of the cause of moon phases. Revealed during the psychomotor modeling activity, the elements were: (1) half of the moon is always lit, except for the relatively rare eclipse; (2) the moon orbits the earth, making one complete revolution approximately every 29.5 days; (3) as the moon revolves around the earth, the moon–earth–sun angle changes; and (4) this causes us to see different portions of the lighted half from earth as the recurring waxing and waning patterns. These instructional activities also were consistent with characteristic #3, as it was shown with the models that a partial lunar eclipse would be required to obtain the false gibbous and other shapes consistent with the popular alternative "shadow" model. Consistent with characteristic #4, these activities were designed to encourage participants to compare the elements of the scientific explanatory framework, shown to be consistent with their empirical data, with their pre-instructional explanatory frameworks. To the extent participants were metacognitively aware of differences in the scientific and their alternative explanatory frameworks, the learning promoted was intentional (Dole & Sinatra, 1998). However, as White (1988) noted, metacognition refers to an inner awareness or process, not an overt behavior. Thus, we claim to have created what we believe are conditions to promote intentional learning, but we have no direct measure of intentionality.

Activities completed in small groups of three or four students frequently included interpretive discussions and interpretive writing. Written responses to questions and prompts were routinely defended in conference with an instructor. This dialogue produced a learning culture of comprehensive interplay between the instructor, students, and the curriculum (Duschl & Gitomer, 1991). Further analysis and application of key concepts were reinforced through homework assignments and examinations. Students also participated in weekly 1-hour, whole-class reviews, which included the study of moon phases on two or three occasions. The total class time devoted to moon study was approximately 10 hours. Activities, questions, and discussion and writing prompts were taken from *Physics by Inquiry* (McDermott, 1996).

Participants and Setting

Twelve women who were included in the earlier study were selected to participate in this longitudinal study. They were undergraduate students majoring in elementary education at a major southeastern research university. Pre- and post-interviews were conducted during the semester the inquiry-based physics course was completed by the participants. At the time of delayed post-interviews, months after the post-interviews, the students were near the end of their teacher preparation program, completing a final block of pedagogy courses before student teaching. Professionally, they were close to a time when they would be working with children on a daily basis and applying their understanding of the targeted science content, moon phases, in teaching children. Because a science methods and materials course was included in the block of pedagogy courses during this semester, the researchers had access to the sample of participants. No experiences within the teacher preparation program in the intervening 6- to 13-month period had dealt with moon phases, and no extraordinary astronomy events involving the moon were reported in the popular media.

Eleven of the 12 participants were white (91.7%) and 1 was black (8.3%). The number of college science credits participants had completed prior to beginning the physics class ranged from 9 to 22 semester-hours, with a mean of 11.8, and no additional science courses were taken by any participant after the physics class. Based on the coding and categorization of the interview data, the performance of the 12 participants in this study was weaker (less scientific) on the post-interview than for the full group. More specifically, 3 weeks after instruction, 66.7% of participants in the current study held a full scientific understanding of the cause of moon phases compared with 77.8% of the 63 participants who received instruction in the initial study (Trundle et al., 2002).

Roles of Researchers

The three members of the research team included a science educator who taught the methods course, a physicist who taught the physics course, and a second science educator who served as a participant-observer and principal investigator. The methods and physics professors collaborated on the general evaluation of the physics course. The principal investigator was a participant-observer in the physics course. Serving as the data collector (Glesne & Peshkin, 1992), she conducted the 36 pre-, post-, and delayed post-interviews. All three researchers independently coded all data and participated in data analysis.

Methods

This longitudinal study is descriptive and interpretive in nature and designed to provide an in-depth view of conceptual understanding over a period of several months. Qualitative methods provided robust, detailed data that captured participants' personal perspectives without constraining their responses to predetermined categories or anticipated responses. Previous research on astronomical phenomena revealed that qualitative methods with interviews, including verbal explanations given while demonstrating with 3D, physical models provide rich, descriptive data on the participants' understanding (Atwood & Atwood, 1995, 1996; Ivarsson, Schoultz, & Saljo, 2002; Trundle et al., 2002). Thus, qualitative data were selected as the most appropriate and informative way to address the research question for this study.

Data Collection and Analysis

Building on previous research, the results of this study were not limited to responses for multiple-choice assessment items. Rather, the results and conclusions for this study were based on verbal responses and use of models during in-depth structured interviews. Each structured interview was audio- and video-taped, and field notes were taken. See Figure 1 for the interview protocol, which includes the nine interview tasks and related questions. The interview responses and field notes were used to understand and document participants' conceptual understandings. During pre-, post-, and delayed post-interviews, each participant was asked questions associated with the nine interview tasks that focused on the cause of moon phases. The interviewer repeated each participant's responses to ensure responses were accurately captured. As each question was answered, the interviewer probed to investigate the participant's conceptual understanding rather than just accepting initial responses. The initial question of what causes moon phases was followed by a request to use 3D models made available to demonstrate ideas in conjunction with verbal explanations as an additional response to the same question. As each participant responded to questions and tasks, the interviewer probed for deeper explanations until no new information was offered. Eight participants were interviewed on a delayed post-instruction basis 6 months after the completion of instruction and four participants were interviewed after a 13-month delay. The difference in delayed post-interviews of 6 and 13 months was simply due to the different time periods that elapsed between the completion of the physics course and enrollment in the science methods and materials course.

Task 1 Explain the cause of moon phases

You probably have noticed that the moon does not always look the same. Sometimes we have what we call a full moon, and at other times the moon is not full. The different appearances of the moon are called moon phases. What do you think causes the phases of the moon? (Probe to get the student to explain.)

Task 2 Use models to show and explain the cause of moon phases

Use these models to explain to me, and show me while you are explaining what you think causes the phases of the moon.

Task 3 Use models to show and explain the cause of a full moon

(Drawing provided to show a representation of the full moon phase. Orange areas represent what we see of the moon of that moon phase.) Take these models and arrange them so that we would see a full moon. Why would the moon appear like this drawing?

Task 4 Use models to show and explain the cause of a new moon

(Drawing provided to show a representation of the new moon phase.) Now arrange them so that we would have a new moon. Why would the moon appear like this drawing?

Task 5 Use models to show and explain the cause of a waning crescent moon

(Drawing provided to show a representation of the crescent moon.) Could we see a moon that looks like this? If so, arrange the models so that we would be able to see a moon that looks like this drawing. Why would the moon appear like this drawing? If not, why not?

Task 6 Use models to show and explain the cause of a waning gibbous moon

Figure 1. Interview protocol. Tasks and questions.

(Drawing provided to show a representation of the gibbous phase.) Could we see a moon that looks like this? If so, arrange the models so that we would be able to see a moon that looks like this drawing. Why would the moon appear like this drawing? If not, why not?

Task 7 Use models to show and explain the cause of a partial lunar eclipse

(Drawing provided to show a representation of the "false gibbous" phase.) Could we see a moon that looks like this? If so, arrange the models so that we would be able to see a moon that looks like this drawing. Why would the moon appear like this drawing? If not, why not?

Task 8 Use models to show and explain a complete cycle of moon phases

Use the models to show me what happens as the moon goes through one complete cycle of phases.

Task 9 Interpret an arrangement of models, draw the appearance of the moon based on the model arrangement, and explain why the moon would appear like the drawing

(Place the models so that the phase of the moon is at the first quarter phase). Look how the models are arranged now. Could the sun, earth and moon be arranged like this? If not, why not? If yes, suppose that this straight pin is located to indicate where you are. With a very clear sky, what would you see when you looked at the moon if the sun, earth, and moon were in this arrangement? Draw what you would see on this sheet. Why would the moon appear like your drawing?

Figure 1. (*Continued*)

Transcripts of audio-tapes made during the interviews were used along with video-tapes during data analysis. The researchers used the constant-comparative method to analyze data (Glaser, 1965; Strauss & Corbin, 1994). The constant-comparative method, first described by Glaser and Strauss (1967), allowed for "joint coding and analysis" of qualitative data (p. 102). Constant-comparative methodology continuously questioned gaps, omissions, and inconsistencies in the data (Glaser, 1965; Glaser & Strauss, 1967). Working in this context, data were collected, analyzed, and coded as an ongoing process.

Previous research (Callison & Wright, 1993; Stahly et al., 1999; Targan, 1988) served to identify the criteria used to describe a scientific understanding and possible alternative conceptions that participants might have. This information was used to develop a "partial framework" (Glaser & Strauss, 1967, p. 45) for analysis in the current study. The partial framework and field notes, which included ideas about data analysis and coding, were used to design the coding sheet and the coding system (Trundle et al., 2002). The coding sheet facilitated analysis and helped standardize coding among researchers (Coffey & Atkinson, 1996). The data coding sheet, which included paraphrases of the interview questions to assistant the researchers during coding, is shown in Figure 2. It should be noted that the coding sheet was used to provide coding guidelines, but it was not allowed to restrict the coding process. New codes that emerged during analysis were added to the original coding system. For examples of codes that emerged during data analysis, see Table 1 (e.g., AltETilt and AltGeo).

Type of Conceptual Understanding______________________________Student______________________________
Researcher **A C T** Number_____________________

1 **What do you think causes the phases of the moon**? Probe to get the student to **explain.**

SciOrb	**SciHaf**	**SciSee**	**SciEMS**	**AltEcl**	**AltRot**	**AltHel**	**AltClo**	**AltFrg**	**AltOth**	**NoCU**	**Inc**

2. **Use these models to explain to me, and show me while you are explaining what you think causes the phases of the moon**.

SciOrb	**SciHaf**	**SciSee**	**SciEMS**	**AltEcl**	**AltRot**	**AltHel**	**AltClo**	**AltFrg**	**AltOth**	**NoCU**	**Inc**

3. (Drawing provided to **show a representation of the full moon phase**. Orange areas represent what we see of the moon from (our city) at that moon phase.) Take these models and **arrange them so that we would see a full moon** in (our city). **Why** would the moon appear like this drawing?

SciOrb	**SciHaf**	**SciSee**	**SciEMS**	**AltEcl**	**AltRot**	**AltHel**	**AltClo**	**AltFrg**	**AltOth**	**NoCU**	**Inc**

4. (Drawing provided to **show a representation of the new moon phase.**) Now **arrange them so that we would have a new moon**. **Why** would the moon appear like this drawing?

SciOrb	**SciHaf**	**SciSee**	**SciEMS**	**AltEcl**	**AltRot**	**AltHel**	**AltClo**	**AltFrg**	**AltOth**	**NoCU**	**Inc**

5. (Drawing provided to **show a representation of the crescent moon**. Show the drawing) **Could we see a moon that looks like this?** If so, arrange the models so that we would be able to see a moon that looks like this drawing. Why would the moon appear like this drawing? If not, why not? **YES** **NO**

SciOrb	**SciHaf**	**SciSee**	**SciEMS**	**AltEcl**	**AltRot**	**AltHel**	**AltClo**	**AltFrg**	**AltOth**	**NoCU**	**Inc**

6. (Drawing provided to **show a representation of the gibbous phase.**) **Could we see a moon that looks like this?** If so, arrange the models so that we would be able to see a moon that looks like this drawing. Why would the moon appear like this drawing? If not, why not? **YES** **NO**

SciOrb	**SciHaf**	**SciSee**	**SciEMS**	**AltEcl**	**AltRot**	**AltHel**	**AltClo**	**AltFrg**	**AltOth**	**NoCU**	**Inc**

7. (Drawing provided to **show a representation of the "false gibbous" phase.**) **Could we see a moon that looks like this?** If so, arrange the models so that we would be able to see a moon that looks like this drawing. Why would the moon appear like this drawing? If not, why not? **YES** **NO**

SciOrb	**SciHaf**	**SciSee**	**SciEMS**	**AltEcl**	**AltRot**	**AltHel**	**AltClo**	**AltFrg**	**AltOth**	**NoCU**	**Inc**

8. **Use the models to show me what happens as the moon goes through one complete cycle of phases.**

SciOrb	**SciHaf**	**SciSee**	**SciEMS**	**AltEcl**	**AltRot**	**AltHel**	**AltClo**	**AltFrg**	**AltOth**	**NoCU**	**Inc**

9. (**Place the models** so that the phase of the moon is approximately at the **first quarter phase**). Look how the models are arranged now. **Could the sun, earth and moon be arranged like this?** If not, why not? If yes, suppose that this straight pin is located to indicate where you are. With a very clear sky, **what would you see** when you looked at the moon if the sun, earth, and moon were in this arrangement? **Draw what you would see on this sheet**. **Why** would the moon appear like your drawing?

YES **NO**

SciOrb	**SciHaf**	**SciSee**	**SciEMS**	**AltEcl**	**AltRot**	**AltHel**	**AltClo**	**AltFrg**	**AltOth**	**NoCU**	**Inc**

Figure 2. Data coding sheet.

Table 1
Codes key

Code	Meaning of Code
SciOrb	Moon orbits earth.
SciHaf	Half of moon illuminated, that half toward the sun.
SciSee	Part of the illuminated half we see determines phase.
SciEMS	Relative positions of earth, sun, and moon determine the part we see.
AltEcl	Dark part of moon in earth's shadow; phases caused by earth's shadow.
AltRot	Earth's rotation on axis causes phases.
AltOth	Reason other than any of above given. Provide description and add to coding system.
AltETilt	Added to the coding system. Tilt of the earth on its axis causes moon phases.
AltGeo	Added to the coding system. Moon phases due to a viewer's geographic position on earth, and people at different geographic locations see different moon phases. For example, if people in North America see a full moon, people on the opposite side of the earth see a new moon. Viewers see a full moon only when the moon is directly aligned with their specific geographic position.

Data analysis began by using the original coding scheme to code responses to the nine interview tasks (Coffey & Atkinson, 1996). The three members of the research team independently analyzed the videotapes and audio-taped transcripts. During data analysis, the researchers noticed how participants' verbal explanations and use of the models aligned or did not align with the coding scheme. As previously noted, the coding scheme was revised as new codes emerged from the data and were integrated into the coding system. This iterative process, consistent with the constant-comparative methodology, continued until the coding scheme became stable. Using the coding scheme, the researchers coded participants' interview responses and recorded the codes on the coding sheet. The researchers also drew diagrams of how the participant placed and moved the models, and they compared the use of models with the participant's verbal explanations.

After each research team member independently analyzed and coded responses to all nine tasks for each individual, the researchers compared the codes within each interview and looked for themes in the codes for the verbal responses and how the participant used the models. The themes were compared with the criteria outlined in Table 2, which includes the types of conceptual understandings and the criteria used to describe them. Then, the participant's responses were categorized based on the type of understanding the codes collectively reflected. The categories of conceptual understandings, which were selected because of being descriptive of and responsive to

Table 2
Types of conceptual understandings and criteria

Categories of Conceptual Understandings	Criteria
Scientific	All four critical elements included: • Half of the moon is illuminated by the sun. • The portion of the illuminated half seen from earth varies over time. • The relative positions of the earth, sun, and moon determine the portion of the lighted half seen from earth. • The moon orbits earth.
Scientific fragments	Included a subset but not all of the four scientific critical elements.
Alternative	Conceptual understandings that are at variance with scientifically accepted norms (Hewson & Hewson, 1983).
Alternative fragments	Included a subset or subsets of alternative conceptual understandings.

the data, were consistent with ‘‘the content model type,’’ which Targan (1988) used in a moon study. Targan defined a conceptual model as ‘‘any group of clearly meaningful propositions intended to explain the lunar phases’’ (p. 83). The term ‘‘type of conceptual understanding’’ was used in the present study instead of ‘‘conceptual model’’ to avoid confusion with the ‘‘analogical models’’ used in the interviews and the ‘‘psychomotor model’’ used in the instruction.

Types of conceptual understanding that were coded included scientific, scientific fragments, alternative, alternative fragments, and no understanding. A scientific understanding was defined as a conception in agreement with scientifically accepted norms. The critical elements required for a scientific coding were identified earlier. If a participant’s responses included one to three, but not all four critical elements, while showing no alternative conceptions, her conceptual understanding was coded as scientific fragments. Note that a fragment here refers to one of four critical elements of the cause of moon phases and not a tiny piece of knowledge, which diSessa (1993) called a p-prim. Consistently showing an understanding that half of the moon is always lit, the moon orbits the earth once about every 29.5 days, or the changes in moon–earth–sun angle change the amount of the lighted half visible from earth as the moon orbits the earth is far more complex than a p-prim.

Alternative conceptions were defined as conceptual understandings at odds with scientifically accepted norms (Hewson & Hewson, 1983). For example, participants were judged to hold alternative conceptual understandings if their responses included propositions such as moon phases are caused by variations in the earth’s shadow being cast onto the moon, or caused by the earth’s rotation on its axis. Participants’ responses were categorized as alternative fragments if the responses were not restricted to only one alternative conception. Participants who did not reveal any information judged to reflect a scientific or alternative conceptual understanding were coded and categorized as having no conceptual understanding for the cause of moon phases.

The researchers then compared the codes and categories for each participant longitudinally across the three interviews. Finally, comparisons were made across participants to identify emergent patterns in the categorizations of conceptual understandings before instruction, after instruction, and months later. This allowed the researchers to draw conclusions about whether conceptual change occurred and how persistent the change was over time.

The research team met periodically throughout the data analysis process to ensure interrater agreement. The three researchers initially agreed on categories of conceptual understanding for 34 of the 36 pre-, post-, and delayed post-interviews, for 94.4% agreement. When a discrepancy arose among researchers’ categorizations, the team reviewed the video-taped interview together, discussed discrepancies, and reached consensus.

In summary, comparisons were made within a single interview, between the verbal responses and the use of models, between each interview and the initial and emerging codes, between the three interviews for each participant, between interviews of the different participants, and between the three researchers for interrater agreement.

Results and Discussion

Results are summarized in Table 3, where pseudonyms are used in displaying the categorizations for each participant. Based on their consistency in verbally responding and using the models, it was inferred that 7 of the 12 participants entered the first interview with an initial explanatory framework reflecting an organized, coherent, nonscientific conceptual understanding. Their understandings were categorized as alternative. Four participants did not consistently use one explanation. Rather they seemed to show little conviction and justification in using two or more alternative explanations. Their responses were categorized as alternative

Table 3
Categorization of conceptual understanding types

Participant	Pre-instruction	Postinstruction, (3 weeks after)	Delayed Postinstruction, (Months After)
Anna	None	Scientific	Scientific
Beth	Alternative	Scientific	Scientific
Cara	Alternative	Scientific	Scientific
DeShea	Alternative fragments	Scientific fragments	Scientific
Emily	Alternative	Scientific fragments	Scientific
Frannie	Alternative	Scientific	Scientific fragments
Georgia	Alternative	Scientific	Alternative
Helen	Alternative fragments	Scientific fragments	Alternative fragments
Izzie	Alternative fragments	Scientific	Scientific
Jasmine	Alternative	Scientific	Scientific
Katie	Alternative	Scientific fragments	Scientific fragments
Lauren	Alternative fragments	Scientific	Alternative fragments

fragments. The remaining participant lacked an explanatory framework for the cause of moon phases, and her conceptual understanding was categorized as none.

The post-instruction interview responses suggest participants had altered their initial explanatory framework to the extent that their responses were scientific in nature, although the explanations of four participants fell short of exhibiting all critical elements of a complete scientific explanation and were categorized as scientific fragments. Thus, all 12 participants showed evidence of holding some scientific conceptual understanding shortly after instruction, and no participant showed evidence of holding an alternative conception.

Nine of the 12 participants showed evidence of continuing to hold some scientific understanding 6 or more months later, while showing no evidence of holding one or more alternative conceptions in the explanatory frameworks. However, two participants utilized two or more alternative conceptions in their explanations, and a third used a single alternative explanation. These participants' explanations were categorized as alternative fragments and alternative, respectively. It is inferred that those who reverted to an alternative explanation had not fully integrated the scientific explanation generated during instruction through a major restructuring of their initial explanatory frameworks. Perhaps the status (Beeth, 1998b; Hennessy, 2003) of the scientific explanation was temporarily raised near the time of instruction, and the alternative explanations were temporarily rendered inert (Bransford, Franks, Vye, & Sherwood, 1989). However, several months removed from the instruction, perhaps the status of the scientific explanation had fallen below that of one or more alternative explanations.

Four patterns in the categorizations of conceptual understandings emerged that describe how participants' understanding persisted or changed during the course of the study. On the basis of interview responses it was inferred that some participants' understanding had changed to scientific by the post-interview and remained stable through the delayed post-interview. This pattern result is growth and stability. Other participants' responses indicated a change to scientific fragments after instruction and the desirable change continued to a full scientific understanding by the delayed post-interview. This pattern of result is continuous growth. Other participants' responses were judged to be scientific on the post-interview, but regressed to scientific fragments or an alternative understanding on the delayed post-interview. We refer to these patterns of results as partial decay and full decay, respectively. A case is provided for each pattern and a brief discussion follows each case.

Growth and Stability

Returning to Table 3, months after instruction, the scientific conceptual understanding for six of the participants was unchanged from the post-interviews and can be described as simply "remaining stable" (Tytler, 1998) or as being "durable" (Georghiades, 2000). Anna, Beth, Cara, Izzie, and Jasmine gave responses that were solidly scientific on both the post- and delayed post-interviews. Excerpts from Beth's interview responses, beginning with her pre-assessment responses, provide a typical example. See Table 1 for explanation of the codes used in the interview excerpts.

Beth, before instruction:

> We might not be able to see all of the moon at certain times of the day because the earth is blocking the moon (**AltEcl**). Then the light's not getting to the moon and we can't see it. If the, like if the sun was here, then all of that light would get to the moon. More light would get to the moon and so we would see more of the moon because it would reflect off. But like right here, only a little bit would get to it; so, we wouldn't see as much of the moon because the earth is blocking it (**AltEcl**). Okay. That's the full moon and the sun's rays would hit the moon and illuminate all of it because there's nothing like the earth between the sun and the moon to like block it (**AltEcl**). And this is the new moon and then this earth is blocking, the earth's blocking all of the sun's rays; so, none of them get to the moon; so we don't see any of the sun, any light reflected moon (**AltEcl**). You wouldn't see any of the moon because the earth's blocking all of the sun's rays (**AltEcl**).

Beth, 3 weeks after instruction:

> I think the position of the moon relative to the earth and sun causes the different phases of the moon (**SciEMS**). Because of how the sun shines on the moon and how we view it from different angles relative to the earth. The moon is rotating counterclockwise around the earth (**SciOrb**) and so it makes the appearance of the moon different. I suppose we can start at a new moon which the moon is going to be right here relative to the sun (holding the moon in the new moon position: **SciEMS**) because the sun's rays are shining off of this part of the moon which is away from the earth (pointing to the side of the moon toward the sun) so we are not, the sun is not reflecting on the side that is towards earth so we cannot see the moon that day because we can't see any of the lit half (**SciHaf**). It's positioned away from earth so we can't see it (**SciSee**) and that's the new moon. And as the moon moves counterclockwise (moving the moon around the earth: **SciOrb**), the moon is also moving relative to the sun (**SciEMS**), we see a waxing moon, which means that we are seeing more and more of the lit half of the moon (**SciSee** and **SciHaf**) and the moon looks like it is slowly becoming bigger. Right here that produces a crescent as we see it from the earth (holding the moon at about a 30° angle in the waxing crescent position). And then it moves more (**SciOrb**) towards at a 90° angle and we see the waxing quarter (**SciEMS** and **SciSee**). And then as it moves further this way (**SciOrb**) we see a waxing gibbous which is almost a full moon (holding the moon at about a 135° angle: **SciEMS**). And then as it moves (**SciOrb**) to 180° it's a full moon which the sun's rays are shining on this whole side that's facing the earth (pointing to the side of the moon positioned toward the earth and sun) and we see all of the lit half (**SciSee** and **SciHaf**).

Beth, months after instruction:

> The phases of the moon are caused by the rotation of the moon around the earth (**SciOrb**). And the sun shines on the moon—it shines on—it always shines on one half of the moon (**SciHaf**), and position of the earth and moon to the sun (**SciEMS**) allows us to see the

> different phases (**SciSee**). And the moon rotates counterclockwise—it rotates counterclockwise around the earth (**SciOrb**). Okay. This is going to be a full moon because the light from the sun is lighting this whole side of the moon. So that's all we see the whole side that is lit (**SciSee**). And that's a whole moon (**SciEMS**). And then it rotates counterclockwise around the earth (**SciOrb**) after the full moon and it goes into the waning phases, which this would be a waning gibbous and then this would be a waning quarter. And this would be a waning crescent and then here it would be a new moon because the sun is lighting this side of the moon and so this half of the moon would not be lighted and it's the side toward us (**SciHaf**). The lighted part is away from us and we can't see it (**SciSee**).

Comparing the post- and delayed post-interview responses for Beth, we infer major restructuring must have occurred from pre-instruction to the post-interview that resulted in the establishment of a stable, scientific explanatory framework. The consistency of both post-interview responses suggests the alternative, nonscientific framework either has been restructured into a scientific understanding, or the scientific explanatory framework has gained higher status (Beeth, 1998b; Hennessy, 2003).

Katie's post-instruction understanding, classified as scientific fragments, also was durable, persisting more than a year later. Three weeks after instruction, and again several months later, her responses suggest she understood that the moon orbits the earth and the position of the sun and moon relative to earth affects the portion of the moon we see from earth. However, her responses did not clearly reveal an understanding that half of the moon is consistently illuminated by the sun. Katie gave no evidence of mixing her initial alternative conception with elements of a scientific conception to create a synthetic model (Vosniadou, 2003). Rather, she seems to have restructured her alternative conception or relegated it to a lower status. However, in the restructuring process, from our perspective but not from hers, she failed to incorporate an important scientific idea into her explanatory framework.

Continuous Growth

The delayed post-interview results for DeShea and Emily showed improvement from scientific fragments to scientific. This type of change in postinstruction understanding has been described by Tytler (1998) simply as "advancing in thinking."

DeShea, before instruction:

> I would say, I'm not really sure about what causes moon phases or a lot of things like that, but I would think that the tilting of the earth's axis (**AltOth: EarthTilt**) and the spinning of the sun and the, you know, the earth around the moon (**AltOrb**). I would say that like, the earth is on its axis (turning the earth model on its axis: **AltRot**) and it tilts around the moon (**AltETilt**). Okay, um, so here's the earth and the, the moon, and as you turn, as the earth turns on the axis (**AltRot**), you can see that like here, it may not show, it may just show part of the moon. And then as it turns some more, it would show the whole moon (turning the earth model on its axis and holding the moon model directly over our city: **AltOth: Geographic Position**), as we, we know, and then, you know, it turns all the time so you're, you're always seeing a different part of the moon and sometimes you don't even see the moon (holding the moon in one place and turning the earth on its axis until our city is turned away from the moon: **AltGeo**).

DeShea, 3 weeks after instruction:

> It keeps going and eventually in 30 days the moon will have gone around the earth one time which makes all of the different phases of the moon (**SciOrb**). The moon rotates around

> the earth (**SciOrb**) that causes the phases of the moon. I'm assuming that it's because like when the moon and the sun are at a certain angle (**SciEMS**), where the moon is according to where it's going around the earth (**SciOrb**), that would be what causes the phase. There would be different angles that the sun would hit the moon causing a different phase (**SciEMS**). That would be a new moon because the angle between the moon and the sun and the earth (holding the moon in a new moon position: **SciEMS**). We don't see the moon at that time because the sun is lighting up the back side, the side opposite us and we can't see it. The side on the moon facing us is dark because the sun's not lighting it. What's causing a new moon, because we can't see any of the lit side of the moon (**SciSee**).

Note one could infer DeShea implied that half of the moon is always lit. However, the authors took a conservative approach to categorization. Because this critical element was not explicitly included by DeShea, she was coded as scientific fragments.

DeShea, months after instruction:

> I believe it's the rotation of the moon around the earth (**SciOrb**). Uh—as the moon rotates around the earth—well, half of the moon is lighted by the sun (**SciHaf**). We may not see the whole thing because of the way it is positioned with the earth and sun (**SciSee** and **SciEMS**). We just see parts of it and sometimes we see more of it or less of it (**SciSee**). It just depends on how the moon is positioned with the earth and sun (**SciEMS**). Okay. At this point we don't see the moon because it is a way it's positioned to the sun (**SciEMS**). We don't see the moon at this point (holding the moon model in a new moon position relative to the sun and earth, **SciEMS**) but as it moves this way—as the—the moon moves—I think it moves this way (moving the moon model around the earth model counterclockwise; **SciOrb**) where we'll see half of it here (holding the moon model at about a 90° angle to the earth and sun models at a first quarter position: **SciSee** and **SciEMS**). We don't see the moon here (pointing to the new moon position). And as it moves around this way we see half of it here (pointing to the first quarter position) and then we see all of it here (moving the moon model to the full moon position at about 180° to the earth and sun: **SciSee** and **SciEMS**).

At this point, DeShea's explanation clearly is scientific.

Like Katie, on the post-interview neither DeShea nor Emily appeared to understand that half of the moon is consistently lit by the sun. However, unlike Katie, DeShea and Emily included this critical element in their explanations 6 or more months later on the delayed assessment. The scientific explanation that was part of the psychomotor modeling activity, including the insight that half of the moon is always lit, except for the relatively rare eclipse. Considering the delayed post-interview results, it seems likely this understanding had been incorporated into the explanatory frameworks of DeShea and Emily during instruction, but it was inert (Bransford et al., 1989; Vosniadou, 2003) on the post-interview. Or, perhaps DeShea and Emily engaged in further restructuring of their explanatory frameworks prior to the post-interviews. Possibly an awareness of the moon in the sky or the appearance of a moon shape in the popular press triggered further restructuring. Although the source of motivation for additional restructuring is unknown, we can say with certainty it was not formal instruction on moon phases in the teacher preparation program.

Partial Decay

Reverting to previously held conceptions has been described by Georghiades (2000) simply as "exhibiting regression" or "conceptual decay." Tytler (1998) described the phenomenon as "regressing in thinking." From these perspectives, 4 of the 12 (33.3%) participants in the current study seemed to exhibit conceptual decay and regression in thinking. One of the participants, Frannie, did not exhibit full decay. Her post-instruction understanding changed from scientific on the post-interview to scientific fragments on the delayed post-interview. This pattern is one of partial conceptual decay. Excerpts from interviews that support these classifications are presented next:

Frannie, before instruction:

> Well, I've always been told in grade school that it was something like the way the earth throws a shadow over the moon (**AltEcl**). Kind of like when we cast a shadow over, or it's, yeah, I think that's what it is. The way that the earth casts a shadow over a moon and it kind of makes it either a crescent or it doesn't cast a shadow and makes it full (**AltEcl**). If the moon's kind of behind the earth or something and uh, the earth kind of blocks the sun (**AltEcl**). The sun kind of might be over here and the moon might be over here, so like, maybe the earth is kind of blocking the sun's light (holding the sun model and on one side of the earth model and the moon model on the opposite side partially behind the earth: **AltEcl**). It's the earth that's making the shadow and the sun's lighting up the moon. And like if the moon were over here and the sun were back here, then the sun's trying to shine, but the earth's there, it can't show the moon all the way, so it kind of makes like a crescent (moving the moon model further behind the earth model and holding the sun model on one side of the earth model and the moon model on the opposite side behind the earth model: **AltEcl**). Or the sun could be like around over here and show the whole moon (moving the sun model and moon model to about a 90° angle with the earth model) because the earth's not blocking the light (**AltEcl**).

Frannie, 3 weeks after instruction:

> And this is a new moon so the sun will be casting light on this half (holding the moon model in a new moon position and pointing to the side of the moon facing the sun: **SciHaf**), but it's the half that we can't see (**SciSee**). So it's completely dark over here (pointing to the side of the moon away from the sun and facing toward earth). The moon's completely dark on our side. There's no light being cast on this half of the moon (pointing to the side of the moon toward the earth). This half is lit (pointing to the side of the moon facing the sun: **SciHaf**), but none from what we can see. The back half, that's facing toward the sun is lit (**SciHaf**). I think it just has to do with the degrees between the moon and sun. I mean, I know it has to do with the degrees between the sun and the moon and their positions (**SciEMS**). The moon is moving, well, the moon is moving around the earth, and it moves around the earth about once every 30 days (**SciOrb**). Well, the moon, it goes, it goes all the way around. I mean the moon circles around the earth. Here the angle's getting larger as like, it's getting larger, the angle's getting larger here as it goes around (moving the moon from a new position toward the full moon position) and then it's going to get to a full moon and then the angle's going to start decreasing again (moving the moon from the full moon position toward the new moon position), until it comes back and it's dark again, this side is dark again (pointing to the side of the moon toward earth) and at any given time a whole half of the moon is lit (**SciHaf**). It's just what we can see of the lit half (**SciSee**) that makes the phases.

Interestingly, Frannie began the post- and delayed post-interviews with an eclipse explanation that she had used during the pre-assessment. When a participant began an interview with an explanation, and then spontaneously changed to an explanation that fell into a different category, the latter category was used if no further wavering occurred in response to repeated probes.

Frannie presented an example of this type of occurrence. This phenomenon suggests the initial explanation had not been restructured but coexisted with the scientific explanation in the explanatory framework. Apparently, the status of each explanation varied, depending on the situation. After the early part of the interviews, Frannie apparently decided the physics class explanation was preferable for this occasion. That portion of the 40-minute delayed post-interview is included in the excerpt that follows.

Frannie, months after instruction:

> In a whole moon the earth is not at all in the way of the sun and the moon (**AltEcl**). They're kind of like here's the sun; here's the moon and it's just like earth is here and not in the way. Then the earth will come in between the sun and the moon to cause the phases. Okay, so here's the earth casting its shadow on the moon right here (**AltEcl**). And so not as much of the moon is showing. And then we have a new moon. In that case it would kind of be like the earth is totally—all of the light from the sun is reflected onto the earth. None of it is getting to the moon. It's the new moon because the sun is showing all its light onto the earth and none of it on the moon. The earth is completely blocking (**AltEcl**). For the crescent it would be kind of like the earth in between—then a little bit of the moon is kind of showing—so the earth is casting its shadow onto it like this and then the sun is showing from there (**AltEcl**). Wait. That can't be right. I'm going to change this here. The sun would be over here and then the earth would—would be over here so we'd be seeing most of the moon. So—so the sun has got to be over here showing all of its light up onto this side. Just a minute. I changed it. We're not in between so the sun is always, half the moon is lighted (**SciHaf**). It's the angle between the sun and moon and earth that causes moon phases (**SciEMS**). I want to go back to a full moon. For a full moon, the sun will be shining down so—we will be seeing the whole moon, this whole side, this whole half where the sun is shining (**SciHaf** and **SciSee**). Then the new moon would be like—the sun is over here, shining off the side on this half of the moon (**SciHaf**) but it's not showing over here on the side where we are. It's on the opposite side so we can't see it (**SciSee**). And then for the crescent because it's just kind of like a very thin part of the lighted half that we can see (**SciHaf** and **SciSee**) and it looks that way because of the angle here. We are only seeing that very thin part because of the angle right here (**SciEMS**). Yeah. I started out talking about shadows and I just changed my mind because I always thought that half of the moon, that half of the moon was lighted no matter where the earth was (**SciHaf**). We just couldn't always see the whole lighted part (**SciSee**). So when we had a full moon, that whole half was lighted and we could see it (**SciHaf** and **SciSee**).

On the delayed post-interview, Frannie implied, but did not explicitly indicate, that the moon orbits the earth. Her understanding was conservatively categorized as scientific fragments because of that omission. The post- and delayed post-interview results suggest Frannie did not exclusively hold a scientific understanding after instruction. Rather she seemed to have a synthetic model in which elements of a scientific explanatory framework coexisted with an alternative conception (Vosniadou, 2002). Her scientific fragments explanation seemed to have only a modestly higher status than the alternative explanation (Beeth, 1998b; Hennessy, 2003). The prospect of Frannie reverting to the eclipse model in her teaching career is a troubling possibility that cannot be discounted.

Full Decay

Based on interview responses, three participants' understanding changed from scientific or scientific fragments to alternative or alternative fragments, from post- to delayed post-interviews.

Before instruction, Georgia seemed to believe that moon phases were due to a viewer's geographic position on earth. She used the models to explain that viewers see a full moon only when the moon is directly aligned with their specific geographic position. Three weeks after instruction, she dropped this perspective in her explanations and exhibited a scientific understanding. Yet, months after instruction, she reverted to her pre-instruction explanations, showing no evidence of scientific understanding at all. Excerpts from Georgia's interview responses follow.

Georgia, before instruction:

> Well, as it moves out of, here's (our city), this would be a full moon (holding the moon directly over our city: **AltGeo**) and as it moves (moving the moon around the earth: **SciOrb**), we're only seeing like part of a moon and then whenever it's completely out of sight (moving the moon away and holding the moon on the opposite side of the earth from our city), it would be no moon (**AltGeo**). And then as it comes back (moving the moon back toward our city: **SciOrb**) we'd start seeing parts of the moon, and then it would be full again (holding the moon directly over our city: **AltGeo**). And whenever we're facing the moon (holding the moon directly over our city), we have a full moon (**AltGeo**) and as it moves (moving the moon around the earth: **SciOrb**) we see different phases of the moon. Whenever it's back here is when we would have a new moon because the moon's on the other side of the earth from us but we can't see it (holding the moon on the opposite side of the earth from our city: **AltGeo**). That would be like another part of the earth would be seeing a full moon. Like that would be a full moon for Australia over here (**AltGeo**).

Georgia, 3 weeks after instruction:

> Allright. The moon's out here. When the moon is at about right here, about 45° from the sun (**SciEMS**), which I'm really bad at degrees; so, bear with me. Okay, when the moon's over here, 45° from the sun (**SciEMS**), we will see a crescent moon (**SciSee**). So, this would be a waxing crescent at about 45° right here (holding the moon in a waxing crescent position) and the moon moves around the earth (**SciOrb**). And here it comes to 90° (**SciEMS**). We see a quarter moon and that's when half of the moon is lit (**SciHaf**) and we see half of the lit half (**SciSee**). Then whenever the moon is at 180° right here (**SciEMS**), half the moon is lit (**SciHaf**) and showing a completely lit half. We see half of it lit, we see all the lit half, which would be a full moon (**SciSee**). Half of the moon is always lit (**SciHaf**). We just may not see all of it all the time (**SciSee**). Then whenever it comes over to the other side as it moves around, it's moving around (**SciOrb**) past a full moon and we'll see the gibbous waning moon and I think it's at approximately 130° here (**SciEMS**). And then at 90° we see a half moon (**SciEMS**) and then at about 45° here we see the waning crescent moon (**SciEMS**). Then we would have a new moon here (**SciEMS**). Whenever it's here is when we would have a new moon. That would be when the moon is on this side of the earth toward the sun and being lit we can't see it because half of it's lit (**SciHaf**), but we can't see the lit half at all (**SciSee**). The side away from earth is lit, but we can't see it because it's away from us (**SciEMS** and **SciSee**).

Georgia, months after instruction:

> Well, as the earth rotates on its axis different parts of the moon are shown to the point where we are looking from (**AltRot** and **AltGeo**). Well, as the earth moves, the moon is—I mean—as the earth moves we see different parts of the moon, due to the earth's positioning to the moon (turning the earth model around on its axis, **AltRot**). Well, as the earth rotates on it's axis—we're down here somewhere and past the moon—right here. I would say that possibly right here we would see all of the moon (turning the earth model around on its

> axis:**AltRot**; and holding the moon model above our city: **AltGeo**). And as the earth turns (turning the earth model around on its axis: **AltRot**), the earth may turn left so that only this small part of the moon would be facing us (holding the moon almost on the opposite side of the earth from our city: **AltGeo**), as the earth rotates (**AltRot**). So this might be a crescent moon or a quarter moon. And as the earth rotates (turning the earth model around on its axis: **AltRot**)—I think it has a lot more to do with the earth rotating (**AltRot**)—I know that one revolution makes a whole day and as it comes back around that's when we usually see the moon and I know further down, we see the angles of the moon to the earth. And that's what causes the length of the phases of the moon and there's 12 months in a year so you get 12 moon phases as it goes right up. And whenever we are in a position that—we can see the moon—a phase occurs. Like right here is a full moon because we're lined up so that (our city) is facing the moon (holding the moon model above our city:**AltGeo**). I know that right here we are turned away from the moon and then we can't see it but another part of the world is seeing a full moon (holding the moon model on the opposite side of the earth from our city:**AltGeo**). So that's a new moon right there and then in Australia is seeing a full moon (**AltGeo**).

It seems likely Georgia added a scientific explanation during instruction but did not sufficiently restructure to eliminate the alternative conception she held before instruction. After instruction, she may have held two explanations, without being metacognitively aware of inconsistencies between the two. Perhaps the post-interview came so near instruction that she selected the physics class model as more appropriate for that occasion. The delayed post-interview came months after the physics class was completed, and in this situation the alternative explanation was applied, perhaps because it was the more strongly held and had higher status at that time (Beeth, 1998b; Hennessy, 2003).

Similarly, Lauren showed no evidence of any scientific understanding a year after instruction, even though her interview responses reflected a scientific understanding in the post-instruction interview, 3 weeks after instruction. In fact, Lauren and Helen showed similar patterns in their three interviews. Before instruction Lauren's several alternative fragments included the views that moon phases are caused by the earth's shadow (eclipse), the earth's rotation on its axis, the earth and moon independently orbiting around the sun in opposite directions, and the sun periodically blocking the view of the moon from earth ("sun blocking"). It is noteworthy that Lauren, and others, used multiple alternative explanations with no apparent awareness of inconsistencies among the explanations. It was disappointing when, months after instruction, Lauren reverted to multiple pre-instruction alternative explanations. Collectively these results suggest that Lauren had little metacognitive awareness in her study of moon phases, and her learning was not intentional.

Alternative fragments initially held by Helen included the earth's rotation on its axis, the orbiting of the sun and moon around the earth, and varying distance between the sun and moon all worked together to cause moon phases. Three weeks after instruction she showed no evidence of holding any of these alternative fragments. Rather, she showed evidence of progress in developing a scientific explanatory framework, only failing to include that the moon orbits the earth. Months after instruction, Helen continued to indicate that the position of the sun and moon relative to the earth affects the portion of the lit half of the moon we see. However, she suggested that, as the sun orbits the earth, the distance between the sun and moon contributes to the cause of moon phases. These delayed post-instruction perspectives seem to reflect a modest variation of her pre-instruction understanding, which we infer was strongly held and resistant to change. Following instruction, Helen seemed to hold a synthetic model likely resulting from insufficient restructuring of her explanatory framework (Vosniadou, 2002). Helen's metacognitive awareness of inconsistencies in her explanatory framework also must have been quite low. A strength of conceptual change interpretations based on Vosniadou's work is that they provide explanations of what does and does not change, including potentially incompatible conceptions that simply coexist.

Conclusions and Implications

The positive post-instruction results reflect impressive growth in scientific understanding for all participants. Further, the desirable conceptual change was durable for the majority of participants at 6 or more months later. However, some participants showed evidence of experiencing partial or full decay in their scientific understanding of the cause of moon phases. Three participants reverted to alternative conceptions initially expressed that apparently were not restructured into a scientific explanatory framework during instruction. Perhaps in these cases, the status of the scientific framework was higher at post-interviews, at which time it was strongly associated with the physics course, and the alternative explanations were relegated to lower status. However, months removed from the physics course, it seems likely the status of the more strongly held alternative explanations was higher and these explanations were dominant. We conclude that these three participants had little or no metacognitive awareness of the inconsistencies between the scientific and alternative models they were holding simultaneously. Interestingly, two of the four persons who provided more than one alternative explanation during the pre-interviews reverted to the same alternative explanations on the delayed post-interview. These persons apparently were not metacognitively aware of inconsistencies between multiple alternative explanations or those explanations and the scientific explanation that emerged during instruction. On the other hand, only one of the seven participants who initially provided evidence of holding one alternative conception on the cause of moon phases was categorized as alternative on the delayed post-interview. Four of the remaining six were solidly scientific, and two were categorized as scientific fragments. Perhaps participants who consistently showed evidence of holding a single coherent, alternative explanatory framework on the pre-assessment were more likely to engage in a comparison of the critical elements of their initial framework and a scientific explanatory framework than persons who initially held multiple, alternative frameworks. If one assumes a single coherent explanation would be more strongly held than two or more inconsistent explanations, then our results do not support the common-sense generalization that more strongly held alternative conceptions are more difficult to change. Rather, holding only one alternative framework may be evidence that a person is more metacognitive and their learning is more intentional. If so, we would expect them to benefit more from the instruction, which appears to be the case.

In a few studies of topics other than moon phases the durability of understanding after instruction has been examined. Tytler's (1998) study of children's conceptions of air pressure included a delayed post-interview 6 months after instruction. The results of Tytler's study are consistent with the findings of the present study in that some children's explanations "remained stable" over the course of several months, whereas other children "regressed" and some "advanced in their thinking."

Attempting to strengthen the initial instruction by encouraging more intentional learning or providing a modest set of instructional activities later in the teacher education program that can encourage intentional learning are two plausible instructional modifications based on our conclusions. Further, we speculate on locations in the instructional sequence where encouraging more metacognitive awareness might be particularly helpful.

We believe the psychomotor modeling activity is particularly critical. Considerable variation was observed in the amount of time and effort students seemed to devote to that activity after the scientific explanation had been identified. The cognitive load for the activity, which provides an opportunity for examining the critical elements of the cause of moon phases and comparing those elements with those constituting one or more alternative frameworks, is judged to be heavy. During the psychomotor modeling activity, some students slowly and repeatedly moved the moon model through a complete orbit, stopping frequently as if to ponder the phase that was being simulated and the conditions that produced it. Other students worked more quickly in moving the moon model through a couple of orbits, and then moved to another activity.

Bereiter and Scardamalia (1989) suggested that students develop strategies to meet the goals of school tasks in ways that economize mental effort and lack the kind of effort leading to intentional learning. Our teaching experience prior to and within this study is consistent with that perspective. It could be fruitful to determine whether participants who economize their efforts are less likely to hold a single, coherent explanatory framework for the cause of moon phases. It has been argued that students should initiate and control their own learning, particularly if it is to be intentional (Brown & Campione, 1994). However, Hatano and Inagaki (2003) suggested, wisely we believe, that learning in school subjects will usually have to be induced socioculturally by teachers and supportive peers. Acting on that suggestion, we have given thought to how we can make what arguably is very good instruction even better.

Consistent with our interpretation of results we conclude that there is a need for new strategies to encourage participants to compare the critical elements of a scientific explanation with alternative explanations they hold. That is, new strategies to promote more metacognitive awareness and intentional learning are required to produce more durable conceptual change (Georghiades, 2000). A recommended addition is to have participants predict, in writing, before the moon study begins, the moon shapes and patterns they expect to observe and also explain, in writing, what causes the changes in observable moon shapes. Participants would then be asked periodically to compare observations and simulation results with their pre-instruction views. Comparisons would be facilitated by the use of small-group discussions and written analyses. We recommend such comparisons be required as a last step in the analysis of 9 weeks of moon observation data and as a last step in the psychomotor modeling activity. The comparisons may help students become aware of how their understanding is consistent or inconsistent with their empirical data.

The McDermott (1996) instructional materials utilized have been judged to be highly consistent with the four characteristics of instruction to promote conceptual change identified earlier (Vosnaidou 1991, 2003). Had we only gathered post-instruction data, we might have concluded all participants' learning had been intentional, and that strong restructuring (Carey, 1988) had occurred in the explanatory frameworks of all participants. However, the delayed post-instruction results indicate the conceptual change evidenced during the post-interviews was not durable months later for some participants. We have attributed the lack of durability largely to unresolved inconsistencies between two or more explanatory frameworks. Ultimately, the broader question of how effectively graduates of a program are able to plan and implement instruction on standards-based moon concepts should be addressed. Determining how we can assure that newly certified teachers will bring a scientific understanding of moon phases to their planning and implementation activities is one of the prerequisites for addressing the broader question. To that end, we have suggested minor modifications to the McDermott instructional materials we utilized. The efficacy of these suggestions should be tested.

We hypothesize that delayed post-instuction results for many other important scientific conceptions that seem to have emerged after instruction would reveal a similar lack of durability as our results on the cause of moon phases, or perhaps even worse. Across the life and earth sciences, we see little instructional material for preservice elementary teachers that is highly consistent with the four characteristics promoting conceptual change, as described earlier. At the same time, we believe facilitating and documenting durable conceptual change should be central to the role of science educators. Thus, we recommend a major commitment to instructional materials development for preservice elementary teachers, with intentional learning in the life and earth sciences the target. Further, we recommend a major commitment from conceptual change researchers to accept the challenges of doing longitudinal research.

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