Preservice Elementary Teachers' Conceptions of Moon Phases before and after Instruction

Kathy Cabe Trundle,[1] Ronald K. Atwood,[2] John E. Christopher[3]

[1]Ohio Resource Center, 1929 Kenny Road, Ohio State University, Columbus, Ohio 43210-1079

[2]112 Taylor Education Building, University of Kentucky, Lexington, Kentucky 40506-0001

[3]Physics Department, University of Kentucky, Lexington, Kentucky 40506-0055

Received 12 June 2001; Accepted 1 November 2001

Abstract: This study focused on the conceptual understandings held by 78 preservice elementary teachers about moon phases, before and after instruction. Participants in the physics groups received instruction on moon phases in an inquiry-based physics course; participants in the methods group received no instruction on moon phases. The instructive effect of two different types of preinstruction interviews also was compared. The instruction on moon phases used in the study is from *Physics by Inquiry* by Lillian McDermott. In the study, the method of inquiry followed a qualitative design, involving classroom observations, document analysis, and structured interviews. Inductive data analysis identified patterns and themes in the participants' conceptual understanding. Results indicate that without the instruction, most preservice teachers were likely to hold alternative conceptions on the cause of moon phases. Participants who had the instruction were much more likely to hold a scientific understanding after instruction. The instruction appears to be more effective in promoting a scientific understanding of moon phases than instruction previously reported in the literature. It also appears that using a three-dimensional model or making two-dimensional drawings during the preinstruction interviews does not have instructive value. © 2002 Wiley Periodicals, Inc. J Res Sci Teach 39: 633–658, 2002

Students come into university science classes with their own ideas about the natural world. They likely have their own understanding about natural phenomena, such as why we have seasons, how traits are inherited from parents by offspring, and what causes moon phases (Ault, 1984a; Baxter, 1989; Brumby, 1984; Driver & Oldham, 1986; Greene, 1990; Kuethe, 1963; Sadler, 1998; Vosniadou, 1991). These preconceived understandings are sometimes naive and nonscientific, although they may make sense to the students. Alternative, or nonscientific,

Correspondence to: K.C. Trundle; E-mail: ktrundle@ohiorc.org
DOI 10.1002/tea.10039
Published online in Wiley InterScience (www.interscience.wiley.com).

conceptions often go unarticulated and unchanged in the science classroom (Hewson & Hewson, 1988).

Understanding the cause of moon phases is a part of scientific literacy and a targeted concept in the *National Science Education Standards* (National Research Council, 1996). More specifically, for Grades kindergarten (K) through 4, students are expected to study the patterns of movement and observable shape changes in the moon. Being able to explain the cause of moon phases is expected for Grades 5–8. Because many elementary schools are K–5, elementary teachers may strive to help students develop a scientific understanding of the concept. Science textbooks at the elementary school level target moon phase concepts for instruction (Abruscato, Fusco, Hassard, Peck, & Strange 1989, Brummett, Lind, Barman, DiSpezio, & Ostlund, 1995; Heil, 1996). Yet, there is evidence that people with varied levels of schooling and training from elementary school through inservice teachers do not understand the cause of moon phases (Callison & Wright, 1993; Cohen, 1982; Dai & Capie, 1990; Sadler, 1987; Schoon, 1992; Schoon, 1995; Stahly, Krockover, & Shepardson, 1999; Targan, 1988; Zeilik, Schau, & Mattern, 1999).

Conceptual understandings and related alternative conceptions about the moon have interested researchers for more than 70 years (Cohen & Kagan, 1979; Jones & Lynch, 1987; Treagust, 1988). Most previous research on this topic (Table 1) has been descriptive (Baxter, 1989; Bisard, Aron, Francek, & Nelson, 1994; Dai & Capie, 1990; Haupt, 1950; Kuethe, 1963; Schoon, 1992; Schoon, 1995) and has focused on the conceptual understandings of elementary through high school students (Baxter, 1989; Haupt, 1950; Sadler, 1987; Stahly et al., 1999). Some studies have included university students (Bisard et al., 1994; Kuethe, 1963; Targan, 1988; Schoon, 1992) but few have focused on preservice teachers and their understanding of moon phases (Callison & Wright, 1993; Dai & Capie, 1990; Schoon, 1995). The results of these studies indicate that most preservice teachers, like the students they are preparing to teach, do not understand the cause of moon phases. Callison and Wright (1993), in a study of 76 elementary preservice teachers, found that without instruction only 6.6% of the participants held a scientific understanding of moon phases. Similarly, 18% of the 122 elementary preservice teachers surveyed by Schoon (1995) understood moon phases, and Dai and Capie (1990) reported similar results in their survey of 174 preservice teachers.

Because educators are charged with developing a scientifically literate society, a potentially serious problem is presented by preservice and inservice teachers who themselves hold alternative conceptions about concepts included in the textbooks they use or that are targeted by the national science education standards. Perhaps elementary teachers can teach younger students about the pattern associated with moon phases without communicating to them an alternative conception the teachers hold, and perhaps not. Popular children's literature about the moon (Asch, 1993; Carle, 1986), which traditionally is used in elementary classrooms, unfortunately may reinforce alternative conceptions about moon phases (Trundle, 2000). In trying to understand the origin of alternative conceptions about moon phases, Ault (1984b) identified the problems associated with the misrepresentation of the moon in children's literature and stated that alternative conceptions about the moon often originate from literature. Although hard data are lacking to validate this assertion or to determine how influential the alternative conceptions of teachers may be on students' conceptual development, the potential for negative effects is clearly there, and it makes logical professional sense to teach preservice teachers about the cause of moon phases.

Previous attempts to modify alternative conceptions on moon phases have met with limited success. In a study of 213 students in Grades 9–12, Sadler (1987) found that 37% of the students surveyed understood the cause of moon phases before instruction, whereas 60% held a scientific understanding after instruction. The results of the Zeilik et al. (1999) survey of 498 college

Table 1
Summary of results from previous studies

Author	Participants	n	Most Common Alternative Conception	% of Participants with Scientific Conception	Data-Gathering Method
Baxter (1989)	9–16-year-old students	120	Eclipse	Not indicated	Interviews ($n = 20$) Multiple choice items ($n = 100$)
Bisard et al. (1994)	Middle school through college students	708	Eclipse (37.6%)	39.2%	Multiple choice items
Callison & Wright (1993)	Elem. preservice teachers	76	Eclipse	Pre = 6.6% Post = 22.4%	Interviews and Targan test
Dai & Capie (1990)	Elem. preservice teachers	174	Eclipse	Not indicated	Multiple choice items
Haupt (1950)	1st-grade students	21	Clouds	0%	Interviews
Kuethe (1963)	Males entering college	100	Eclipse (70%)	Not indicated	Multiple choice items
Sadler (1987)	9–12th-grade students	213	Eclipse (37%)	Pre = 37% Post = 60%	Multiple choice items
Schoon (1992)	College students	226	Eclipse (69.5%)	26.1%	Multiple choice items
Schoon (1992)	5th, 8th, and 11th-grade and college students	1213	Eclipse (48.1%)	34.3%	Multiple choice items
Schoon (1995)	Elem. preservice teachers	122	Eclipse (62.3%)	18%	Multiple choice items
Stahly et al. (1999)	3rd-grade students	4	Nonscientific	0%	Interviews and observations
Targan (1988)	College nonscience majors	61	Eclipse Pre = 14.8% Post = 8.2%	Pre = 1.6% Post = 18%	Open-ended questions with written responses
Zeilik et al. (1999)	College astronomy students	498	Eclipse (28%)	Pre = 31% Post = 60%	Multiple choice items

astronomy students were similar to those reported by Sadler, with 31% of the students holding a scientific understanding before instruction and 60% after instruction. Of the 61 college nonscience majors in Targan's (1988) study, 1.6% were judged to hold a scientific understanding before instruction compared with 18% after instruction. Callison and Wright's (1993) study also supports the findings that participants' conceptual understandings of moon phases can be changed by instruction. Of the 64 elementary preservice teachers in their study, 6.6% were judged to hold a scientific understanding before instruction, whereas 22.4% were judged to be scientific after instruction. These disparate findings are considered in the Results section.

Purpose of Study

A review of the literature revealed voids in the research on moon phases in three areas. First, in assessing understanding of the cause of moon phases, no previous studies used a three-dimensional, analogic model in structured interviews. Clearly, many scientific phenomena, including the phases of the moon, are three-dimensional. Yet, classroom instruction, textbook diagrams, and previous research studies about astronomy phenomena, including moon phases, traditionally have relied on two-dimensional diagrams as models (Baxter, 1989; Callison & Wright, 1993; Dai & Capie, 1990; Nussbaum, 1979; Schoon, 1992; Targan, 1988; Treagust & Smith, 1989; Vosniadou & Brewer, 1992). Research indicates that students cannot easily relate a two-dimensional diagram to three-dimensional astronomy phenomena (Kelsey, 1980). Consistent with this view, the use of models along with verbal explanations in structured interviews has been recommended by other researchers (Atwood & Atwood, 1995, 1996; Stahly et al., 1999) as a preferred data-gathering procedure for this type of study. Thus, it was expected that the use of three-dimensional models in structured interviews would yield richer descriptions of alternative conceptions and help identify alternative conceptions on moon phases not previously reported in the literature. Second, no previous study attempted to affect nonscientific conceptions of moon phases by using an inquiry sequence of instructional activities and strategies that are widely available in published form, as is the sequence used in this study from *Physics by Inquiry* (McDermott, 1996). Using locally developed multiple choice questions with alternative conceptions embedded in the distractor options, the investigators in this study did a preliminary evaluation of the instruction. The results were positive, producing optimism for evidence of effects based on assessment by structured individual interviews. Finally, no previous study focused on the potential instructional value of the interview process when used as a pretest. Previous research had suggested the use of three-dimensional models could have instructive value (Atwood & Atwood, 1995, 1996). During pilot interviews, the investigators in this study had observed some students begin a verbal explanation while manipulating models, stop a line of explanation, and shift to a different explanation. It was unclear whether use of the models was providing insight that positively influenced responses in the interviews. Determining whether the interview process in the pretest has instructive value seemed essential to determining the effect of the instructional sequences. To meet these three needs, the following research questions were addressed through a qualitative research design.

1. Before instruction, what are the types of conceptual understandings held by elementary preservice teachers about the cause of moon phases?
2. How do elementary preservice teachers' conceptual understandings of moon phases differ after completion of the instruction on this topic?
3. On the cause of moon phases, how do the conceptual understandings of elementary preservice teachers who completed the instruction compare with those who did not?

4. Does using a three-dimensional model or making a two-dimensional drawing during preinstruction interviews have instructional value?

The research questions guided the design of the study and the analysis of data. Questions 1 and 2 are central to the study. It was hypothesized that preinstruction interviews would yield similar but richer descriptions than previously reported in preinstruction research, and postinterviews would show positive effects. Questions 3 and 4 were included to increase confidence that post-results could be attributed to the instruction. Qualitative analyses were used to address these questions and judge the validity of the hypothesis.

Methodology

The qualitative design of the study (Glesne & Peshkin, 1992; Mason, 1996) involved classroom observations, document analysis, and structured interviews (Rubin & Rubin, 1995). Interview questions based on key concepts and previous research (Callison & Wright, 1993; Dai & Capie, 1990; Schoon, 1992; Stahly et al., 1999; Targan, 1988) were written by the research team members (see Appendix for the student interview protocol). As individual participants responded to the standardized set of interview questions, the interviewer probed for deeper explanations until no new information seemed to come from the responses. Participants were first asked to provide verbal explanations of their thinking about the cause of moon phases. Subsequently, some were asked to use a three-dimensional, analogic model of the sun, earth, and moon to complement their verbal explanations; others were asked to draw diagrams to complement their verbal explanations.

A review of the literature revealed that much of the prior research on conceptual understanding of moon phases used surveys requiring written explanations or responses on a small number of multiple choice items (Baxter, 1989; Bisard et al., 1994; Callison & Wright, 1993; Dai & Capie, 1990; Kuethe, 1963; Sadler, 1987; Schoon, 1992, 1995; Targan, 1988; Zeilik et al., 1999). Multiple choice items with distractors that reflect alternative conceptions have yielded useful data. However, the information they provide is limited by the data-gathering process in that participants may hold alternative conceptual understandings about moon phases that are not represented on the multiple choice instruments. Moreover, previous research on the cause of night and day and the seasons (Atwood & Atwood, 1995, 1996) revealed that written explanations tend to focus on declarative knowledge, whereas verbal explanations given while demonstrating with physical models provide richer data on the subjects' understanding. The advantage of being able to probe a verbal explanation during an individual interview seems obvious.

In the present study, qualitative methods provided rich, detailed data that captured participants' personal perspectives without constraining their responses to predetermined categories or anticipated responses. Inductive data analysis identified patterns and themes in the participants' conceptual understandings of moon phases. Data analyses included organizing the data and searching for patterns to describe and display participants' conceptual understandings (Coffey & Atkinson, 1996).

Participants and Setting

The two groups of students recruited to participate in this study were undergraduate elementary education majors at a major southeastern research university. Students in the physics groups were enrolled in a physics course designed for them and being phased in as a requirement in the elementary education program. The physics groups received the inquiry instruction targeting moon phase concepts. A review of the literature revealed no previous studies had taken a qualitative look at the moon phase conceptions of preservice teachers before and after studying the topic as the students did in this inquiry-based physics course. Methods group students were first-semester seniors enrolled in an elementary science methods course. The methods group shared professional aspirations and a history of general studies coursework with the physics groups, except some students had not taken the inquiry-based physics course during its phase-in period. Only those students in the methods class who had not taken the physics course were included in this study.

One hundred four students were enrolled in four sections of the physics class over two semesters. Sixty-three physics students (60.6%) volunteered to participate in the study. The physics students enrolled during one semester were randomly assigned to Physics Group A or B, and the students from the other semester were labeled Physics Group C. One member of a physics group was in the first year of the program, and the others were in the second or third year of the 4-year program. Fifty-six students were enrolled in two sections of the 4th-year methods course, and 37 (66%) volunteered to participate in the study. Of the 37 methods students who volunteered, only the 15 students who had not taken the inquiry-based physics course were included in the methods group of this study. The methods group had received no instruction on moon phases in the methods course at the time they were interviewed.

Ninety-one percent of the 78 participants were females; 91% were White, and the others were African-American (6.4%), Asian-American (1.3%), and Hispanic-American (1.3%). The number of college science credits that participants in the physics groups had completed before beginning the physics class ranged from zero to 28 semester hours, with a mean of 10.2. Science credits completed by the methods students ranged from 4 to 29 semester hours, with a mean of 14.4.

Roles of Researchers

One of the research team members taught the physics course, and another taught the methods course. The third member of the team served as a participant observer and principal investigator.

The physics professor participated by agreeing to have observations made of his teaching. He also was interviewed to probe his thinking about his classroom practices and his methods for teaching about moon phases. He reviewed and edited questions subsequently used in student interviews and analyzed data from all student interviews.

The methods professor participated in the study by advising on the interview model and questions, interviewing 7 of the 78 participants, analyzing data from all of the student interviews, and supervising the experimental design and implementation of the project. The physics and methods professors had collaborated on the design and general evaluation of the physics course.

The principal investigator functioned as participant observer in the physics course. She participated as a member of the class and as principal data collector (Glesne & Peshkin, 1992). She observed and recorded events as they occurred during the class sessions on Astronomy by Sight, and she studied the context of the classroom, noting the locations of people, objects, and space. The field notes included descriptions of the participants, their interactions with others and objects, their words, and their gestures. Field notes also included thoughts, impressions, and feelings. Because some of the 78 participants were interviewed twice, a total of 120 interviews were conducted during data gathering. The participant observer served as the interviewer for 113 of those interviews. She also interviewed the physics professor, gathered documents, and analyzed data.

Data Collection

A structured protocol was used to interview participants (see Appendix). Data were obtained for the Physics Groups A and B participants before the beginning and 3 weeks after the completion of instruction on moon phases. The Physics Group C participants were interviewed once, 3 weeks after instruction. Data from Physics Group C were used to address Research Question 4. The methods group was interviewed once. Data from the methods group were used to address Research Question 3. Physics Group A used the three-dimensional model while providing verbal explanations to communicate their understanding during both the pre- and post-instructional interviews. Physics Group B made two-dimensional drawings while providing verbal explanations to communicate their understanding during the preinstructional interview and used the model with verbal explanation during the postinterview. As previously stated, Physics Group C and the methods group were interviewed only once and they used the three-dimensional model with verbal explanation. The type and timing of interviews for all groups are summarized in Table 2.

Following a qualitative, structured interview format (Rubin & Rubin, 1995), participants initially were asked to state what they thought caused the phases of the moon. Interviews were audiotape recorded as well as videotape recorded, and notes were taken during each interview. During the interviews, the interviewer first repeated what participants said instead of paraphrasing their ideas to make sure that what they were saying was accurately captured. Follow-up questions included "How is that happening?" "What do you mean?" and "Please explain a little more about that." After each initial response to an interview question, the interviewer probed to determine what the participant understood about a concept rather than just accepting the initial response, which may have been given without much thought or detail. After the initial question, participants were asked either to use the three-dimensional model or to draw two-dimensional diagrams to demonstrate their ideas while providing verbal explanations. As participants responded to the interview task, the interviewer probed for deeper explanations until no new information seemed to come from the respondents.

Data Analysis

Audiotapes of the interviews were transcribed and the transcripts were used along with the videotapes during analysis by the researchers. An inductive process was used to identify themes and patterns that described the student participants' conceptual understandings of moon phases. Data analysis included organizing the data and searching for patterns to describe and display participants' conceptual understandings (Coffey & Atkinson, 1996).

Table 2
Type and timing of participants' interviews

Group	Type of Instruction on Moon Phases	No. of Interviews	Type of Preinstructional Interview	Type of Postinstructional Interview
Physics Group A	Inquiry-based physics instruction	2	3D model with verbal explanations	3D model with verbal explanations
Physics Group B	Inquiry-based physics instruction	2	2D drawings with verbal explanations	3D model with verbal explanations
Physics Group C	Inquiry-based physics instruction	1	None	3D model with verbal explanations
Methods group	No instruction before interview	1	3D model with verbal explanations	None

To make the findings more reliable, all three members of the research team independently viewed the videotapes, reviewed transcripts, and analyzed participants' interview responses. The team met periodically to calibrate analyses and ensure interrater reliability. The three researchers initially agreed on 113 of the 120 interviews, for 94.2% agreement. When discrepancies arose across individual analyses, the team reviewed the videotaped interviews together, discussed discrepancies in coding, and reached consensus on the type of conceptual understanding. The researchers rarely disagreed on the overall type of conceptual understanding held by a participant (i.e., scientific, alternative, alternative fragments).

To decrease coding bias, an effort was made to keep the groupings of participants unknown to the researchers. The order of analyses was randomized across groups to decrease the probability of researchers identifying participants by group. This effort was successful in keeping team members from differentiating between pre- and postinterviews for the physics groups. However, the physics instructor knew who had taken the course and was able to differentiate between the physics groups and the methods group participants. Nonetheless, his coding was consistent across groups and seldom differed from that of the other two coders.

Consensus data from the three investigators' analyses of the videotaped interviews and the interview transcripts were coded (Coffey & Atkinson, 1996) and recorded on a coding sheet to facilitate analysis of the data. The coding sheet design and code system were based on previous related research studies (Callison & Wright, 1993; Stahly et al., 1999; Targan, 1988) and field notes, which included ideas about data analysis and coding that emerged during the interviews. Coding sheets were used to expedite analyses by organizing the key points of analysis and standardizing the coding system among all three researchers. The coding sheets were used as guidelines but they were not allowed to be restrict coding. Codes that emerged during analyses were added to the coding system. Participant responses were coded by the conceptual understanding reflected. The codes are identified and defined in Table 3.

Instructional Context

Participants in the physics groups received instruction on moon phases while enrolled in a physics course designed for preservice elementary teachers, meeting 2 hours for 3 days per

Table 3
Definition of codes

Meaning of Code	Code
The moon orbits Earth	SciOrb
Half of moon is illuminated; that half is facing the sun	SciHaf
The part of the illuminated half we see determines the phase	SciSee
Relative positions of Earth, sun, and moon determine the part we see	SciEMS
Dark part of moon in Earth's shadow; phases caused by Earth's shadow	AltEcl
Earth's rotation on axis causes phases	AltRot
Clouds or weather conditions cause phases	AltClo
More than one of above Alt given (List)	AltFrg
Reason other than any of above Alt given	AltOth
No conceptual understanding evident or no response given	NoCU
Not enough information in response to be able to code	Inc

week. Instruction on moon phases was included in the topic, Astronomy by Sight, one of six topics addressed in the course. During 5 hours of class sessions each week, small groups of three students engaged in investigations accompanied and followed by interpretive discussions and interpretive writing. Written responses by group members to questions and prompts were routinely defended in conference with an instructor, producing a learning culture of comprehensive interplay among the instructor, students, and curriculum (Duschl & Gitomer, 1991). Further analysis and application were promoted through almost daily homework assignments and occasional examinations. Students also participated in weekly 1-hour, whole-class reviews. The source of investigative activities, questions, and other prompts for interpretive discussion and writing was *Physics by Inquiry* (McDermott, 1996). An examination of these materials suggests that the developers are aware of the most frequently held alternative conceptions for each major topic addressed. Furthermore, it appears the developers have included activities leading students to make observations at odds with the alternative conceptions. Students in the course were pushed repeatedly to construct conceptual models that were consistent with their observations and to modify their model when new observations were inconsistent with it. Thus, some popular misconceptions were confronted. The physics instructor has been an innovator in introductory physics instruction for many years. He is highly skilled in using inquiry techniques and has a strong commitment to teacher preparation.

The study of moon phases was spread over most of the semester-long physics course with little class time devoted to it during the first 2 months. Early in the semesters of this study, the physics students were given a chart and asked to record daily observations of the moon whenever they could during 9 weeks. The chart consisted of rows of square shapes; each square contained a pair of circles. The appearance of the moon, including its orientation to the horizon, could be recorded at two different times during the same day by darkening a portion of the circle that corresponded to the part of the moon that was visible. Space was provided to record the time and date of each observation, and the approximate angle made by the sun, observer, and moon, if the sun was visible at the time. Students also were asked to identify the cardinal direction, such as east or southeast, in which the moon was observed, if they knew the direction. Once or twice each week, two to three volunteers took a few minutes of class time to share their latest observations by drawing and writing data on the board. Discrepancies among observers, usually due to differences in estimating the angles, were noted. Class members were polled frequently to determine the extent of their agreement with the shared observations, but no final resolution of differences in reports was attempted at that time.

After about 2 months, the students began to use their data to work through the first five exercises and experiments in Section 5, Phases of the Moon, in Volume 1 of *Physics by Inquiry* (McDermott, 1996). Highlights of instruction from the section follow.

Initially the students pooled their observations for each day, numbered the days consecutively, and looked for patterns. Extensive interpretive discussions continued to occur in small groups. First for single-day observations, and then for the entire 2-month observation period, students were asked if they observed variations and patterns in the appearance of the moon and in the angle made by the moon, observer, and sun. Students were required to support responses with their data. After describing daily and monthly patterns, students sketched the sequence of shapes over a month and noted the moon was not visible during some 24-hour periods, even when the sky was clear. At this point the different shapes were named phases; the students were told that the period in the monthly cycle when the moon cannot be seen is called the new moon; and names were associated with drawings of the crescent, quarter, gibbous, and full moon phases. Furthermore, the terms *waxing*, *waning*, and *first and third quarters* were associated with appropriate examples from the students' observations. Having established the order of the phases during a synodic period, and the relationship between the phases and the angle made by the moon, observer, and sun, students predicted if and where the moon could be observed in a given phase at a particular time of day.

Subsequently, the classroom was darkened except for an incandescent bulb placed at about eye level. An instructor, working with about six students at a time, modeled how to use the bulb, a white sphere, and the observer's head to represent relationships among the sun, moon, and earth, respectively. Standing several meters from the bulb, the instructor and each student held a white sphere just above their heads with their arms fully extended. They slowly rotated their entire body, noting that the brightly lit portion of the white sphere changed for the holder in a way that is similar to the changes in moon phases as the moon orbits the earth. Each student held a white sphere and personally moved it through as many complete revolutions as needed to verify this. The direction the white sphere had to be revolved to produce a simulated sequence of phases consistent with the students' observations of the moon was noted. The moon, observer, and sun angles from observational data were compared with the angles observed in the modeling activity. Limitations of this physical model also were noted, including scale and the fact that only one rotation of the head (representing the earth) occurred as the white sphere (representing the moon) made one complete revolution around the head. The bulb, head, and white sphere also were used to represent what happens during a lunar eclipse.

At this point, the groups of students were asked to formulate and write an explanation for the cause of moon phases. The explanation, or conceptual model, was required to fit the data that had been obtained over 2 months of directly observing the moon and the psychomotor modeling activity. Also, students were asked to consider changes in the earth's shadow on the moon as the cause of moon phases. This was an attempt to use observational data to confront and discredit a particular commonly held alternative conception.

The preceding instructional sequence provided the structure for students to confront whatever conceptual understanding they held about the cause of moon phases. What emerged from each group at the end of the sequence was a scientific explanation of the cause of moon phases. The extent to which a scientific understanding subsequently would be reflected in individual postassessment interviews, using a physical model that had not been used in the instructional sequence, was the major focus of Research Questions 2 and 3.

Models

As previously noted, a limitation identified in the research comes from the types of models used in earlier studies. Of the studies using models, the majority used two-dimensional diagrams (Baxter, 1989; Callison & Wright, 1993; Dai & Capie, 1990; Targan, 1988). In this study, the physical model used in the instruction included a lighted incandescent bulb representing the sun, the observer's head representing the earth, and a 10-cm white sphere representing the moon. The observer was an internal component of the model, viewing everything from an earth perspective. All light used to make observations came from the incandescent bulb representing the sun. The scale of the activity was on the order of several meters as the white sphere was revolved around the observer's head. In contrast, the three-dimensional physical model used during the interviews included a 10-cm yellow plastic sphere resting in a small cradle representing the sun, a 3-cm white sphere representing the earth, and a 1-cm white sphere representing the moon. The observer (i.e., the student) for the interview situation was external to the components of the model. All of the light used to see the parts of the model came from an external source, i.e., ambient room light. The scale of the model components used during the interview was less than a meter.

Results

The criteria used to classify conceptual understandings into types are provided in Table 4. The results of using the categories with all groups are summarized in Table 5. To help the reader understand the results of the study, excerpts from two of the participants' interview responses and the corresponding assigned codes are provided. Participants' responses are indicated by the students' number, and the interviewer's questions and comments are designated by "R." Responses that were coded are in bold with the code listed in parentheses. See Table 3 for a definition of codes. Descriptions of how participants used the model are in italics.

Student 2 (2), the physics groups, 3 weeks after instruction:

Interviewer (R): You've probably noticed the moon doesn't always look the same. And sometimes we see what we call a full moon and at other times the moon is not full.

2: Uh huh.

R: What do you think causes those phases of the moon?

2: Well, it is, the sun, the moon, the light that we see on the moon is from the sun. And **the moon is always half lit (SciHaf) but we can only see parts of it depending on our position with the moon (SciSee).**

R: Okay. You said it depends on our position to the moon.

2: Uh huh.

Table 4
Types of conceptual understanding and criteria used to describe conceptual understandings

Type of Conceptual Understandings	Criteria
Scientific	All four scientific criteria included: • Half of the moon is illuminated by the sun • The portion of the llluminated 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 with alternative fragment	Met all four scientific criteria but also indicted that Earth's rotation on its axis contributed to causing the phases
Scientific fragments	Included a subset but not all of the four scientific criteria
Alternative	Conceptual understandings which are at variance with scientifically accepted norms (Hewson & Hewson, 1983)
Alternative eclipse	The earth's shadow causes the moon phases
Alternative Earth's rotation	The earth's rotation on its axis causes the moon phases
Alternative cloud	Cloud cover causes moon phases
Alternative fragments	Included a subset or subsets of alternative conceptual understandings
Alternative other	Response is alternative but does not fit with predetermined codes. Descriptions of key ideas from the response were listed on the coding sheet
None	No conceptual understanding evident, no response given, or not enough information in response to be able to code

Table 5
Frequencies of types of conceptual understanding for all groups

Type of Conceptual Understanding	Physics Group A ($n = 21$) Before Instruction Freq. (%)	Physics Group A ($n = 21$) 3 Weeks after Instruction Freq. (%)	Physics Group B ($n = 21$) Before Instruction Freq. (%)	Physics Group B ($n = 21$) 3 Weeks after Instruction Freq. (%)	Physics Group C ($n = 21$) 3 Weeks after Instruction Freq. (%)	Methods Group ($n = 15$) No Instruction Freq. (%)
Scientific	2 (9.5%)	11 (52.4%)	0 (0%)	17 (80.9%)	15 (71.5%)	0 (0%)
Scientific with alternative fragment	0 (0%)	4 (19%)	0 (0%)	0 (0%)	2 (9.5%)	0 (0%)
Scientific fragments	1 (4.8%)	5 (23.8%)	0 (0%)	3 (14.3%)	2 (9.5%)	0 (0%)
Alternative	12 (57.1%)	0 (0%)	16 (76.2%)	0 (0%)	2 (9.5%)	8 (53.3%)
Alternative fragments	6 (28.6%)	1 (4.8%)	4 (19%)	1 (4.8%)	0 (0%)	6 (40%)
None	0 (0%)	0 (0%)	1 (4.8%)	0 (0%)	0 (0%)	1 (6.7%)

R: Okay, what's going to cause a change in that phase?

2: **The moon going around the earth (SciOrb).**

R: Okay. And how's the moon going around the earth?

2: Counterclockwise.

R: And how is that causing the phases of the moon to change?

2: Well, whenever it's, **whenever the moon is next to, or between the earth and the sun**, which is not really between, it's not like it's in between blocking anything from us, it's kind of above us, but **we won't see anything. It will be a new moon, because the part of the moon that's lit from the sun is on the other side of the moon (SciEMS).** So, we can't see any light. And **then as the moon travels around (SciOrb) we slowly begin to see more and more light on the moon until it gets all the way over here where the sun and the moon, and the earth and the moon are kind of like in a line type thing. And we can see a full moon then (SciEMS).**

R: Okay. They are in a line.

2: I think so. But not like, not so much that the earth hides the light from the sun. **It depends on where the moon is to the earth (SciEMS).**

R: All right, okay. So, the, it depends on where the moon is to the earth.

2: Uh huh.

R: You said the moon is going around the earth counter-clockwise.

2: Right.

R: You said half the moon's always lit.

2: Uh huh.

R: Okay. I'd like for you to use this model to show me and explain to me what you think causes the phases of the moon.

2: Okay. Well, the moon kind of sits up from the earth a little bit. It's not like down here directly in a line with the sun. It kind of sits up here. *(Participant held moon component in her right hand slightly above the earth component and between the earth and sun components.)* And the earth is always spinning like this. *(Participant rotated the earth component on its axis.)* And it makes one full spin every day while it's moving around the sun. And so, this is spinning but I'm not going to spin it the whole time.

R: Okay. How does that spinning affect the moon phases?

2: Well, it affects what we see because, like, if part of the day we're here, we're going to see the moon, but the moon kind of is going around so there's sometimes when the moon is in a certain phase where we see it at night and sometimes it's a certain phase we see during the day.

R: Okay. So, the rotation right there that you were showing me, or the movement of the earth, how does that affect the moon?

2: Nothing, really. Just, it affects, it affects our light, if it's day or night and when we see the moon.

R: Okay.

2: And the angle from, **the angle that the sun is at to the moon is what causes the phases (SciEMS)** and how we see it and it, it stays in that angle all day. So, when it's a full moon, for example, it's going, it's going to be at 180° from the sun which should be like a straight line. *(Participant arranged components so that the sun, earth, and moon represented the full moon position.)* So, we're going to see it when we are night-time back here. Because then we won't see. . .when the sun sets, the moon rises for us. And when the, when the sun rises the moon sets. So, but what it does as far as the moon, is. . .it goes around us like this. *(Participant revolved moon component around the earth component in a counterclockwise circular motion.)* **And it goes around one full circle every 30 days (SciOrb).** So, as we're moving, so is the moon and it affects how we see it. *(Participant arranged components in a waxing crescent moon position, with the sun, earth, and moon at an approximate 45° angle. She pointed to the side of the moon toward the sun.)* **Like right here, this part, this half of**

the moon is going to be lit (SciHaf), but we're just going to be able to see a little part of it over here (SciSee). *(Participant pointed to the part of the moon that would be visible from Earth.)* And that's when it's waxing. And then once you get over here it's first quarter. *(Participant moved the moon component in a counterclockwise motion to the first quarter position, with the sun, earth, and moon in approximately 90°.)* Then it's, over here is full. *(Participant moved the moon component in a counterclockwise motion to the full moon position.)* And then it's third quarter. *(Participant moved the moon component in a counterclockwise motion to the third quarter position, with the sun, earth, and moon in approximately 90°.)* And here it's new. *(Participant moved the moon component in a counterclockwise motion to the new moon position.)*

Further probes continued to produce consistent responses that satisfactorily addressed the four scientific criteria identified in Table 4, so that the student's responses were judged to reflect a scientific conception.

Student 18, the physics groups, before instruction:

R: What do you think causes the phases of the moon?

18: Uh, when the earth rotates around the sun, then, uh, **whenever the earth gets in the path between the sun and the moon, then the earth makes a shadow on the moon (AltEcl)** and that probably lets them make how the moon is fuller. **When it's full there's not as much of a shadow. When it's not full, that's just how much shadow the earth makes (AltEcl).**

R: So when the earth gets in the path between the sun and the moon, there's a shadow from the earth.

18: Um-mm.

R: So when the moon is not full, it's because of the shadow of the earth?

18: Yes.

R: I would like for you to use this model and explain to me and show me while you're explaining what you think causes the phases of the moon.

18: Okay. The earth is always spinning on its axis *(participant rotated the earth component on its axis)* and the moon is going around like this. *(Participant revolved the moon component in a clockwise motion around the earth component.)* And as the earth, and as the moon spins around, well, as the earth spins around, too, **at different points, the earth is going to be between the sun and the moon (AltEcl).** *(Participant held the moon component in a waning gibbous position.)*

R: Uh uh.

18: And so, **whenever the earth gets in between here, it's going to create a shadow on the moon (AltEcl).** So from where I am, you might only see just a little part of the moon because the earth is in the way. And then 'cause it keeps spinning, that's why there're different phases as it spins. It would cause **at different points, whenever the earth was between the sun and the moon is when it's going to make the shadow (AltEcl).**

R: Okay. So when the earth is between the sun and the moon. . . . And show me an example of that.

18: Right. If it was like this, and here's us right here, and here's the sun. *(Participant held the moon component in a waning gibbous position.)* Well, part of the **earth might be, might create a shadow on the moon (AltEcl).**

R: Uh-huh.

18: And so **we'd only be able to see a portion of it.**

R: Okay. And the portion that we'd see would be . . . which part?

18: That would be **the part that's not in the shadow (AltEcl).**

R: Okay. So the part we're seeing is what's not in the shadow?

18: What's not in the shadow.

R: Okay. All right, thanks. Now show me how that would happen for a complete cycle of moon phases and talk to me about that.

18: As you're moving, **here's where the earth is getting in the way. Here's where it's directly in alignment with the moon and the sun (AltEcl).** *(Participant held the moon component in a total lunar eclipse position.)* And then here's where it's passing through. *(Participant moved the moon component to a third quarter moon position.)* **Here you'd be able to see a full moon, because the earth isn't in the path of the sun and the moon (AltEcl).**

R: Um-mm.

Further probes revealed a consistent explanation and the student's responses were judged to reflect the alternative conception that the moon's phases are caused by changes in the earth's shadow on the moon. This alternative conception is coded as AltEcl in Table 3.

Preinstruction Results

Research Question 1. The preinstruction data for Physics Groups A and B and the methods group (Table 5) were analyzed in response to the first research question: Before instruction, what are the types of conceptual understandings held by elementary preservice teachers about the cause of moon phases? Students' responses indicated that without instruction most elementary preservice teachers likely held alternative conceptions of the cause of moon phases. Most participants in Physics Groups A and B (38 of 42 participants; 90.5%) provided responses suggesting they held alternative conceptual understandings or alternative fragments before instruction. Students' responses for the methods group also support this finding, because almost all of those participants (14 of 15 participants; 93.3%) provided responses suggesting they held alternative conceptual understandings or alternative fragments. As hypothesized, this finding is consistent with the results of five other studies of over 1800 subjects, including preservice teachers and elementary school through college students (Dai & Capie, 1990; Kuethe, 1963; Sadler, 1987; Schoon, 1992, 1995). The finding that a majority of the persons assessed, including preservice teachers who had no instruction on the cause of moon phases, held alternative conceptual understandings clearly indicates the magnitude and pervasiveness of the problem. Furthermore, the finding provides a strong basis for predicting that other preservice teachers who have not had appropriate instruction hold nonscientific conceptions about the cause of moon phases.

Participants who were judged to hold alternative conceptions seemed to believe propositions such as the following: moon phases are caused by the earth's shadow being cast onto the moon (eclipse); the earth's rotation on its axis causes the phases; or the moon's orbit around earth and the moon's position relative to a given vantage point on earth causes the phases. The frequencies of alternative conceptual understandings identified in this study are included in Table 6. Other researchers who have reported finding specific alternative conceptions also are identified in Table 6.

Preservice teachers who were judged to hold alternative conceptions about the cause of moon phases were most likely to believe that the earth's shadow causes the phases of the moon (eclipse). The most frequently encountered alternative conception within all groups of participants was that the earth's shadow causes the phases of the moon (eclipse). This finding is consistent with the results of 11 other studies, involving over 3000 participants at all levels of schooling (Baxter, 1989; Bisard et al., 1994; Callison & Wright, 1993; Cohen, 1982; Dai & Capie, 1990; Kuethe, 1963; Sadler, 1987; Schoon, 1992, 1995; Targan, 1988; Zeilik et al., 1999).

Without instruction most preservice elementary teachers did not understand that the moon orbits the earth. In fact, 35 of the 57 participants (61.4%) of the preinstruction Physics Groups A and B and the methods group did not seem to understand that the moon orbits the earth. Previous research did not document the frequency of this particular deficiency. Without instruction, most preservice elementary teachers also did not understand that half of the moon always is illuminated by the sun, except for the infrequent eclipse. Fifty-three of the 57 participants (93%) did not understand that during a typical cycle of phases the sun's light illuminates half of the moon—the side facing the sun—for the entire period. The frequency of this deficiency also had not been documented by previous research. We suspect that persons who lack an understanding of these two key ideas are unlikely to see a problem with the popular eclipse alternative conception.

Postinstruction Results

Research Question 2. The preinstruction and postinstruction data from Physics Groups A and B were used to respond to the second research question: How do conceptual understandings of moon phases differ after completion of the instruction on this topic? After completion of the study of moon phases in an inquiry-based physics course, elementary preservice teachers'

Table 6
Frequencies of alternative conceptual understandings

Alternative Conceptual Understanding	Physics Group A before Instruction	Physics Group B before Instruction	Methods Group, No Instruction	Total	Finding Reported by Other Researchers
Earth's shadow on moon (eclipse)	4	9	5	18	11 studies identified in this report
Earth's rotation on its axis	1	4	1	6	Stahly et al. (1999) Targan (1988)
Moon's position relative to different geographic locations on Earth	2		1	3	Callison & Wright (1993) Stahly et al. (1999)
Clouds	1			1	Baxter (1989) Bisard et al. (1994) Callison & Wright (1993) Haupt (1950) Stahly et al. (1999)
Planet's (other than Earth) shadow on moon		1		1	Baxter (1989)
Earth's tilt		1		1	Callison & Wright (1993)
Sun's shadow on moon				0	Callison & Wright (1993)
Sun's orbit of Earth and moon	1	1		2	Not previously reported
Varying amount of light from sun to moon	1			1	Not previously reported
How directly the sun shines on Earth	1			1	Not previously reported
Varying distance between sun and moon When moon is closer to sun = full moon	1			1	Not previously reported
Varying distance between Earth and moon When moon is closer to Earth = full moon			1	1	Not previously reported

responses were likely to reflect a more scientific understanding of the cause of moon phases. As indicated earlier, the conceptual understandings revealed before instruction in responses by participants in Physics Groups A and B were mostly alternative or alternative fragments (38 of 42; 90.5%). After instruction, most participants' conceptual understandings (40 of 42; 95.2%) were classified as scientific, scientific with an alternative fragment, or scientific fragments. More specifically, the conceptual understandings of 28 of 42 (66.7%) participants were classified as scientific, 4 of 42 (9.5%) as scientific with alternative fragments, and 8 of 42 (19%) as scientific fragments. Although the ultimate goal was to have students express a scientific understanding, we considered notable progress toward a scientific understanding, reflected by scientific with an alternative fragment and scientific fragment classifications, to be important. Only 2 of the 42 participants (4.8%) were identified as holding alternative or alternative fragments after instruction.

After instruction, most preservice elementary teachers seemed to understand that the moon orbits the earth, and that during a typical cycle of phases, half of the moon always is illuminated by the sun. After instruction, 60 of the 63 participants (95.2%) in the physics groups provided responses and used the model in ways indicating they understood that the moon orbits earth. Furthermore, 55 of the 63 participants (87.3%) seemed to understand that the sun's light illuminates half of the moon—the side facing the sun—during a typical cycle of phases. These understandings are incompatible with the popular eclipse alternative conception, and could be important in rejecting that conception.

Research Question 3. In response to Research Question 3, postinstruction data from all participants in the physics groups were compared with the methods group data. Participants who had the instruction were much more likely to provide evidence of holding a scientific conceptual understanding than participants who did not have the instruction. Again, we considered progress toward a scientific understanding to be a positive result. Three weeks after instruction on the phases of the moon, 59 of 63 participants (93.7%) in the physics groups provided evidence of holding scientific, scientific with an alternative fragment, or scientific fragments. More specifically, 43 of the 63 participants (68.3%) provided evidence of holding a scientific conception. Another 6 participants (9.5%) showed evidence of a scientific understanding based on the four criteria, but they also mentioned the effects of the earth's rotation in the cause of moon phases. Because these participants met all four criteria for scientific classification, their responses were labeled as scientific with an alternative fragment. Another 10 participants (15.9%) were identified as holding scientific fragments. These participants met one or more, but not all four, of the scientific criteria in their responses. Only 4 participants (6.3%) were classified as showing an alternative or alternative fragment conceptual understanding 3 weeks after instruction.

The only student in Physics Group A identified as holding alternative fragments after instruction included a particularly interesting fragment in her postinstruction responses. During the preinstruction interview she had expressed the view that clouds cause moon phases. However, after instruction her verbal explanation and use of the model indicated a belief that the moon and sun rise and set relative to a horizon that is separate from the earth. Both her pre- and postinstruction responses are consistent with those earlier reported for elementary children. Stahly et al. (1999) and Haupt (1950) found that third and first graders, respectively, used a cloud model to explain moon phases. The horizontal sky finding is consistent with results reported in a study of children in Grades 4–8 (Nussbaum, 1979).

None of the participants in the methods group—the group that did not receive the instruction—provided evidence of holding a scientific understanding of moon phases. This finding provides further evidence that an interview using the model does not have instructive value; the postinstruction results for the physics groups can be attributed to the instruction in the physics course.

Collectively, the postinstruction results served to validate our hypothesis of positive instructional effects. Other studies (Callison & Wright, 1993; Sadler, 1987; Stahly et al., 1999; Targan, 1988; Zeilik et al., 1999) also showed positive changes after instruction, but not of this magnitude. The percentages of participants showing scientific understanding (not including scientific fragments from the present study) after instruction for this and other studies are summarized in Table 7. Whereas a majority of participants in this study who had instruction provided evidence of holding a scientific conceptual understanding of moon phases, two previously cited studies, Callison and Wright (1993) and Targan (1988), reported much less success. More specifically, Targan reported only 11 of 61 participants (18%) in his study held a scientific

Table 7
Results compared with other studies

Researchers	Participants	No. in Sample (n)	Showing Scientific* Conception before Instruction	Showing Scienfitic* Conception after Instruction
Current study Physics Group A	Elem. preservice teachers	21	9.5%	71.4%
Current study Physics Group B	Elem. preservice teachers	21	0%	80.9%
Current study Physics Group C	Elem. preservice teachers	21	Not assessed	80.9%
Callison & Wright	Elem. preservice teachers	76	6.6%	22.4%
Targan	College nonscience majors	61	1.6%	18%
Sadler[†]	9–12th graders	213	37%	60%
Zeilik et al.[†]	College astronomy students	498	31%	60%

*Includes scientific and scientific with alternative fragment.

[†]Data collected using multiple choice items.

understanding after instruction, whereas 17 of 76 participants (22.4%) in Callison and Wright's study were identified as having a scientific understanding after instruction.

Although the instruction used in other studies probably share some common elements with the instruction in this study, it is not possible to make precise comparisons owing to the limited descriptions of instruction in reports of the other studies. Some of the other studies involved the participants in making daily moon observations over 1 month (Callison & Wright, 1993; Targan, 1988). In contrast, the physics students in this study made and recorded daily moon observations over 2 months, shared data on a weekly basis, and organized and interpreted data to identify patterns. The physics students also described daily and monthly patterns verbally and in writing, and they sketched a sequence of shapes of moon phases. The physics instructor engaged the students in interpretive discussion and provided concept labels for the phases. The students then participated in the psychomotor modeling activity. Finally, they expressed orally and in writing their understandings of the causes of moon phases. Their explanations were consistent with 2 months of observational data and the psychomotor modeling activity. Other studies have involved students in similar psychomotor modeling activities (Callison & Wright, 1993; Targan, 1988; Stahly et al., 1999). However, the physics students in the present study also wrote and orally explained their understandings of the causes of moon phases, and they compared their 2 months of observational data with the modeling activity.

The interview and written response strategies used in the present study and two of the studies identified above (Callison & Wright, 1993; Targan, 1988) are demanding in that they ask students to describe their thinking fully. Two other studies focusing on conceptual understanding of moon phases before and after instruction employed a small number of multiple choice items in gathering data. The multiple choice assessment approach limits student choices and thereby limits misconceptions used to classify students' conceptual understanding. Furthermore, students do not have to generate an explanation and respond to probes. Using multiple choice items, Sadler (1987) found that 37% of 213 students in 9th through 12th grade held a scientific understanding before instruction and 60% after instruction. Zeilik et al. (1999) found that 31% of 498 college astronomy students held a scientific understanding before instruction and 60% after instruction. Findings from these two studies using forced choice data indicate more preinstruction scientific understanding, less postinstruction scientific understanding, and less conceptual change than the present study.

Research Question 4. To understand the potential instructive value of using models during data gathering, and in response to the fourth research question, the postinstruction results for Physics Groups A and B were compared with those of Physics Group C. All three groups used the three-dimensional model during the postinstruction interviews. Participants in Physics Group A also used the model during the preinstruction interview, whereas participants in Physics Group B made two-dimensional drawings in the preinstruction interview. Data were gathered for Physics Group C only through the postinstruction interview. It appears that using a three-dimensional model or making two-dimensional drawings during preinstruction interviews did not have instructive value. Fifteen of 21 of the participants in Physics Group A (71.4%) and 17 of 21 of the participants in Physics Group B (80.9%) were judged to hold a scientific conception after instruction. The postinstruction results for Physics Group C revealed 17 of 21 participants (80.9%) provided responses reflecting a scientific conception. These data also suggest using the three-dimensional models on both pre- and postassessment did not have instructional value.

Summary and Implications

As expected, preinstruction data tended to be consistent with previous research in that without instruction most preservice elementary teachers provided evidence of holding a nonscientific understanding of moon phases. More specifically, the cause of moon phases was most often attributed to the earth's shadow (eclipse model) followed by the earth's rotation on its axis and the moon's position relative to different geographic locations on Earth. However, five alternative conceptions not identified previously in the literature were identified (see Table 6). Also, previous preinstruction research did not reveal the surprising 61.4% of preservice elementary teachers who did not understand that the moon revolves around the earth. Text explanations of moon phases typically include the declarative knowledge that the moon makes one complete trip around the earth in about a month. If one assumes study participants have encountered that fact, the encounter does not seem to have affected construction of an understanding of the phenomenon. It should be noted, however, that the popular eclipse model might not require understanding that the moon orbits the earth. Some participants, who were judged to be holding the eclipse model, moved the model of the moon from just beyond one side of the earth model to behind the earth model and out again on the other side of the earth model in such a way that would create a waxing crescent, a new moon, and a waning crescent. They seemed unaware, or unaffected, by the prospect of getting a phase they had never actually observed, such as a false gibbous. Furthermore, they indicated they would be able to see a full moon when the moon moved from behind the earth—to a gibbous position—so that none of the earth's shadow was falling on it. These back and forth movements behind the earth and out again typically swept out about one-sixth of a full orbit. The two-dimensional drawings in texts of the sun, moon, and earth may well reinforce the notion of these three objects being in the same plane. That possibility should be investigated. Another focus of future research should be the effects of drawings in texts that show the moon in eight different positions around the earth, e.g., waxing crescent, first quarter, and waxing gibbous. Typically, these drawings show half of the moon as being lit in each of the eight positions. The finding that 93% of participants before instruction did not understand that half of the moon is always lit during a typical cycle of phases suggests whatever instruction these participants had received on this important idea was not effective. The extent to which this particular conceptual understanding is lacking had not been documented in previous research.

After instruction, most participants showed evidence of holding a scientific conception or of showing more scientific fragments of understanding than they had shown before instruction. These results were more positive than expected, and much more positive than those reported in previous research where similar assessment measures were used. In speculating on why this particular instruction was so successful on an absolute basis, as well as relative to previously reported instructional efforts, several factors seem important. First, most people, including preservice elementary teachers, likely have had limited moon data to consider. Although sighted adults surely have observed a full moon and less than a full moon on numerous occasions, it is unlikely they have made careful, systematic moon observations over 2 months, shared the observations, and collaborated with others to identify patterns in their data. We think that was important. The monthly recurring sequence of phases, along with the psychomotor modeling experiences, were considered by participants as they engaged in conversations to construct a plausible explanation of what causes moon phases. This was another important and perhaps unique element of the instruction. We infer that this sequence of direct experiences and interpretive sense-making discussions was highly effective in enabling participants to construct a scientific understanding of the cause of moon phases. The instruction clearly is consistent with important views on ways to facilitate the construction of understanding (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Vygotsky, 1962).

Considering these results and the availability of the instructional sequence in *Physics by Inquiry* (McDermott, 1996), these materials are recommended as a logical starting point for persons interested in providing instruction on moon phases. We think it likely the instructor's expertise and commitment were ideally suited to using the instructional sequence as intended in the present study. However, because the instructional sequence and expectations are so clearly described in *Physics by Inquiry*, we predict that instructors with less experience in inquiry teaching who have a commitment to learn will be able to use the sequence successfully. We recommend expanded trials to test that prediction, and perhaps to investigate potential teacher effects.

Although we are impressed with the positive instructional results, we are concerned with a negative finding. Six persons across all groups were classified as scientific with alternative fragment, and all were classified as such based on postinstruction data. All six persons met the four criteria necessary to be classified as scientific, but they also indicated the earth's rotation on its axis contributes to the cause of moon phases (AltRot). Four of these participants were in Physics Group A and were interviewed twice. One of these persons had given an AltRot response at the preinstruction interview and held on to it at the postinstruction interview, while providing what otherwise was a scientific explanation. However, three participants added the AltRot view to an otherwise scientific perspective on the postinstruction interviews. Stahly et al. (1999) reported a similar finding after instruction with third-grade students. In the present study, we speculate that the psychomotor modeling activity used during instruction could be the source of this troubling result. In it, the earth model (the observer's head) makes only one complete rotation for the observer to view the simulated changes in phases, whereas the moon model is revolved through one complete revolution and one complete cycle of phases. This limitation was identified for students at the time the psychomotor model was used. However, verbal explanations may not have been effective for a few participants. That is, direct manipulation of the models may have been a greater influence in constructing an understanding than a verbal statement on a limitation of the modeling activity. The potential effects of this particular psychomotor modeling activity should be investigated. Of course, Earth's rotation does affect the rising and setting of the moon, as well as when the moon can be seen from different geographic locations on Earth. In these specific ways, the earth's rotation is associated with moon phases. During the instruction, students were asked to discuss when the moon in a particular phase rises and sets. These discussions collectively may have influenced some participants to include the earth's rotation in their postinstruction explanation of the cause of moon phases.

The finding that using a three-dimensional model or making two-dimensional drawings during preinstruction interviews did not appear to have instructive value is important beyond the major function of evaluating instructional efforts. The average time for each interview using the model was approximately 30 minutes, compared with an average time of about an hour for each interview in which drawings were made. Furthermore, using the model to describe a three-dimensional phenomenon seemed to be easier and more comfortable for the participants, and it resulted in richer responses. Also, the use of the model required less researcher time during the data analysis and it yielded higher interrater agreement. The interrater agreement of analysis for the interviews that involved three-dimensional models was 97.8% compared with 76.2% for those that involved drawings. Collectively, these benefits argue for using three-dimensional models when studying moon phases or similar phenomena in future research.

Effective instruction on the cause of moon phases is demanding and time-consuming. Does it produce lasting changes? Do elementary teachers use it effectively? Currently, little information exists on the effects of conceptual change instruction over an extended period. Longitudinal studies are recommended to describe the persistence of conceptual understanding of the cause of moon phases after instruction. Ultimately, relationships among teachers' conceptual understanding of moon phases, willingness to teach the topic in their classrooms, and effectiveness in teaching the topic to fifth-grade students and beyond also should be investigated.

Driver (1991) argued that teachers must take into account students' preconceived ideas. As a logical extension, teacher preparation programs must address alternative conceptions of standards-based science concepts that are held by teachers and prospective teachers. Content does matter. Teachers' conceptual understanding of concepts they are expected to teach does matter. This study provides strong evidence for the effectiveness of a particular instructional sequence to address phases of the moon, an important component of standards-based content. The sequence has been sufficiently described so that others who choose to do so can use it.

Appendix: Student Interviews

Statements made to students are in bold type.

Sequence

- Introduction
- Informed consent
- Interview
- Data Sheet

Introduction

Thank the student for participating.

The purposes of my research project are to help me understand what preservice teachers think about moon phases and to improve the effectiveness of instruction about

moon phases. As far as this interview goes, there are no right or wrong answers because I just want to understand what you think about moon phases. Your answers will not be considered in determining your grade in your physics/methods class.

During this interview, I will ask you questions to which you will respond. Your answers will be audiotaped and videotaped. Some of the questions will require you to use a model to explain your answers. Do you have any questions?

Interview Questions

1. **You probably have noticed that the moon does not always look the same. For example, sometimes we can see what we call a "full moon" and at other times the moon is not full. What do you think causes the phases of the moon?**
2. Probe to get the student to explain what he or she thinks causes the phases of the moon. (e.g., **Explain to me how something could block the moon to cause the phases. What could be blocking the moon? Explain how that happens**).
3. **These model components represent the sun, earth, and moon. For practical reasons, they are not to scale in size or relative distances from each other. I want you to use this model to explain to me, and show me while you are explaining what you think causes the phases of the moon.** If the student says that clouds cause the phases of the moon, a piece of cotton will be provided for the cloud component.
4. (Drawing provided to show what the full moon phase looks like. Orange areas represent what we see of the moon at that moon phase.) **Take the model and arrange it so that we would see a full moon. Why would the moon appear like this drawing?**
5. (Drawing provided to show what the new moon phase looks like.) **Now arrange them so that we would have a new moon. Why would the moon appear like this drawing?**
6. (Drawing provided to show what the crescent moon phase looks like. Show the drawing.) **Could we see a moon that looks like this? If so, arrange the model 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?**
7. (Drawing provided to show what the gibbous phase looks like.) **Could we see a moon that looks like this? If so, arrange the model 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?**
8. (Drawing provided to show what the "false gibbous" phase looks like.) **Could we see a moon that looks like this? If so, arrange the model 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?**
9. **Use the model to show me what happens as the moon goes through one complete cycle of phases.**
10. (Place the model components so that the phase of the moon is approximately at the first quarter phase). **Look how the model is 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 where you are. With a 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?**

References

Abruscato, J., Fusco, J., Hassard, J., Peck, D., & Strange, J. (1989). Holt science. Austin, TX: Holt, Rinehart, and Winston.

Asch, F. (1993). Moonbear. New York: Little Simon.

Atwood, V.A. & Atwood, R.K. (1995). Preservice elementary teachers' conceptions of what causes day and night. School Science and Mathematics, 95, 290–294.

Atwood, R.K. & Atwood, V.A. (1996). Preservice elementary teachers' conceptions of the causes of seasons. Journal of Research in Science Teaching, 33, 553–563.

Ault, C.R. (1984a). The everyday perspective of familiar astronomical events. Journal of Geological Education, 32, 89–91.

Ault, C.R. (1984b). Intelligently wrong: Some comments on children's misconceptions. Science and Children, 21, 22–24.

Baxter, J. (1989). Children's understanding of familiar astronomical events. International Journal of Science Education, 11, 502–513.

Bisard, W.J., Aron, R.H., Francek, M.A., & Nelson, B.D. (1994). Assessing selected physical science and earth science misconceptions of middle school through university preservice teachers. Journal of College Science Teaching, 24, 38–42.

Brumby, M. (1984). Misconceptions about the concept of natural selection by medical biology students. Science Education, 68, 493–503.

Brummett, D.C., Lind, K.K., Barman, C.R., DiSpezio, M.A., & Ostlund, K.L. (1995). Destinations in science. Menlo Park, CA: Addison-Wesley.

Callison, P.L. & Wright, E.L. (1993, April). The effect of teaching strategies using models on preservice elementary teachers' conceptions about earth-sun-moon relationships. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta, GA.

Carle, E. (1986). Papa, please get the moon for me. Singapore: Simon & Schuster Books for Young Readers.

Coffey, A. & Atkinson, P. (1996). Making sense of qualitative data: Complementary research strategies. Thousand Oaks, CA: Sage.

Cohen, M.R. (1982, February). How can sunlight hit the moon if we are in the dark?: Teachers' concepts of phases of the moon. Paper presented at the seventh annual Henry Lester Smith Conference on Education Research, Bloomington, IN.

Cohen, M.R. & Kagan, M.H. (1979). Where does the old moon go? The Science Teacher, 46, 22–23.

Dai, M. & Capie, W. (1990, April). Misconceptions held by the preservice teachers in Taiwan. Paper presented at the annual meeting of the National Association of Research in Science Teaching, Atlanta, GA.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. Educational Researcher, 24, 5–12.

Driver, R. & Oldham, V. (1986). A constructivist approach to curriculum development in science. Studies in Science Education, 13, 105–122.

Driver, R. (1991). Culture clash: Children and science. New Scientist, 46–48.

Duschl, R.A. & Gitomer, D.H. (1991). Epistemological perspectives on conceptual change: Implications for educational practice. Journal of Research in Science Teaching, 28, 839–858.

Glesne, C. & Peshkin, A. (1992). Becoming qualitative researchers: An introduction. White Plains, NY: Longman.

Greene, E.D. (1990). The logic of university students' misunderstanding of natural selection. Journal of Research in Science Teaching, 27, 875–885.

Haupt, G.W. (1950). First grade concepts of the moon. Science Education, 34, 224–234.

Heil, D. (1996). Discover the world. Menlo Park, California: Scott Foresman.

Hewson, M.G. & Hewson, P.W. (1983). Effect of instruction using students' prior knowledge and conceptual change strategies on science learning. Journal of Research in Science Teaching, 20, 731–743.

Hewson, P.W. & Hewson, M.G.A.B. (1988). An appropriate conception of teaching science: A view from studies of science learning. Science Education, 72, 597–614.

Jones, B.L. & Lynch, P.P. (1987). Children's conceptions of the earth, sun, and moon. International Journal of Science Education, 9, 43–53.

Kelsey, L.J.G. (1980). The performance of college astronomy students on two of Piaget's projective infralogical grouping tasks and their relationship to problems dealing with phases of the moon. Unpublished doctoral dissertation, University of Iowa.

Kuethe, J.L. (1963). Science concepts: A study of "sophisticated" errors. Science Education, 47, 361–364.

Mason, J. (1996). Qualitative researching. Thousand Oaks, CA: Sage.

McDermott, L.C. (1996). Physics by inquiry. New York: Wiley.

National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.

Nussbaum, J. (1979). Children's conceptions of the earth as a cosmic body: A cross age study. Science Education, 63, 83–93.

Rubin, H.J. & Rubin, I.S. (1995). Qualitative interviewing: The art of hearing data. Thousand Oaks, CA: Sage.

Sadler, P.M. (1987). Misconceptions in astronomy. Proceedings of the Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics (pp. 422–425). Ithaca, NY: Cornell University.

Sadler, P.M. (1998). Psychometric models of student conceptions in science: Reconciling qualitative studies and distractor-driven assessment instruments. Journal of Research in Science Teaching, 35, 265–296.

Schoon, K.J. (1992). Students' alternative conceptions of earth and space. Journal of Geological Education, 40, 209–214.

Schoon, K.J. (1995). The origin and extent of alternative conceptions in the earth and space sciences: A survey of pre-service elementary teachers. Journal of Elementary Science Education, 7, 27–46.

Stahly, L.L., Krockover, G.H., & Shepardson, D.P. (1999). Third grade students' ideas about lunar phases. Journal of Research in Science Teaching, 36, 159–177.

Targan, D. (1988). The assimilation and accommodation of concepts in astronomy. Unpublished doctoral dissertation, University of Minnesota, Minneapolis.

Treagust, D.F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. International Journal of Science Education, 10, 159–169.

Treagust, D.F. & Smith, C.L. (1989). Secondary students' understanding of gravity and the motion of planets. School Science and Mathematics, 89, 380–391.

Trundle, K.C. (2000, January). Misrepresentation of the moon. Paper presented at the annual meeting of the Association for the Education of Teachers in Science, Akron, Ohio.

Vosniadou, S. (1991). Designing curricula for conceptual restructuring: Lessons from the study of knowledge acquisition in astronomy. Journal of Curriculum Studies, 23, 219–237.

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

Vygotsky, L.S. (1962). Thought and language. Cambridge, MA: MIT Press.

Zeilik, M., Schau, C., & Mattern, N. (1999). Conceptual astronomy: Replicating conceptual gains, probing attitude changes across three semesters. American Journal of Physics, 67, 923–927.