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The Use of a Computer Simulation to Promote Scientific Conceptions of Moon Phases

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Abstract: This study described the conceptual understandings of 50 early childhood (Pre-K-3) preservice teachers about standards-based lunar concepts before and after inquiry-based instruction utilizing educational technology. The instructional intervention integrated the planetarium software *Starry Night Backyard*^{TM} with instruction on moon phases from *Physics by Inquiry* by McDermott (1996). Data sources included drawings, interviews, and a lunar shapes card sort. Videotapes of participants' interviews were used along with the drawings and card sorting responses during data analysis. The various data were analyzed via a constant comparative method in order to produce profiles of each participant's pre- and postinstruction conceptual understandings of moon phases. Results indicated that before instruction none of the participants understood the cause of moon phases, and none were able to draw both scientific moon shapes and sequences. After the instruction with technology integration, most participants (82%) held a scientific understanding of the cause of moon phases and were able to draw scientific shapes and sequences (80%). The results of this study demonstrate that a well-designed computer simulation used within a conceptual change model of instruction can be very effective in promoting scientific understandings.
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Since the 1970s, researchers have realized that children, before they ever receive formal instruction, enter elementary school with substantial information about the physical world (Vosniadou, 1999). Unfortunately, students' preinstructional understandings are often at variance with scientifically accepted norms (Champagne & Klopfer, 1983; Driver & Oldham, 1986; Osborne & Freyberg, 1985; Palmer, 2001; Strommen, 1995; Trend, 2001). Previous research indicates that non-scientific or alternative conceptions can be persistent, and changes resulting from science instruction often are different from intended effects (Hewson, 1981; Hewson & Hewson, 1983; Nussbaum & Novak, 1982).

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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). 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. Furthermore, these studies highlight the persistent nature of elementary, secondary, and college students' alternative conceptions about lunar phases.

Understanding lunar concepts is a part of scientific literacy targeted in the *National Science Education Standards* (National Research Council, 1996). More specifically, for grades K-4, students are expected to study the patterns of movement and observable shape changes in the moon. Explaining the cause of moon phases is an expectation for grades 5–8 (Table 1). If teachers are expected to facilitate the work of elementary children in observing, describing, and finding patterns in moon shapes, they should have a scientific understanding of the phenomenon themselves.

Since traditional science instruction for moon phase concepts has unsuccessfully relied heavily on didactic textbook-based approaches, science educators have consistently called for more student-centered instruction that involves making daily moon observations for several weeks and analyzing the data (Abell, George, & Martini, 2002; McDermott, 1996; Trundle, Atwood, & Christopher, 2002, 2004, 2006, 2007a,b). Unfortunately, this type of science instruction can be time consuming, overly frustrating for students, and could even place students in unsafe situations. For example, even those teachers who want to teach lunar phases more experientially may not be able to devote the several weeks of data collection necessary to record the requisite one to two lunar cycles. Further, students often experience high degrees of frustration in making consistent observations each day and even in finding the moon in the first place. Finally, asking young children to go outside at night may create unsafe situations. Overall, these issues combine to make a theoretically effective instructional strategy problematic in actual implementation. This is where planetarium software can potentially make a difference.

Planetarium software programs like *Starry Night Backyard*™ (version 1.0) (used in this study) address the aforementioned implementation issues associated with teaching moon phases experientially. They accomplish this by allowing students to make accurate observations in a realistic simulated environment and to collect more moon data in a shorter period of time. These programs feature easy-to-use graphic interfaces and provide accurate representations of the day and night skies. The software allows the user to make observations from any location on earth over any time period and from any direction or perspective. Additionally, the software can facilitate students' development of scientific understandings by freeing their observations from typical moon-viewing frustrations associated with weather conditions and obstructions from tall buildings, mountains, and trees. Thus, planetarium programs have the potential to promote inquiry instruction while mitigating the impractical time requirements of typical experiential approaches (Trundle & Bell, 2003). However, despite the potential advantages of planetarium software, and

Table 1
NSES earth and space science standards-fundamental concepts.

Grades K-4	Grades 5–8
The moon moves across the sky on a daily basis much like the sun The observable shape of the moon changes from day to day in a cycle that lasts about a month	Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses

the fact these programs have been available for microcomputers since the mid-1980s, the authors are aware of no research into the efficacy of using planetarium software to teach astronomical concepts.

Starry Night Backyard (and other planetarium software) belongs to a class of computer programs known as simulations. Computer simulations are programs based on a scientific model of a system or process (de Jong & Van Joolingen, 1998). These simulations allow students to make accurate observations of phenomena that could otherwise be completed only in the real world or in some cases not at all. The computer simulation experience ranges from a variety of dynamic two- and three-dimensional desktop settings to full immersion virtual reality systems. Previous research has demonstrated the effectiveness of computer simulations in facilitating student learning. For example, a recent meta-analysis of 42 studies reporting the effectiveness of various types of computer-assisted instruction on student achievement found computer simulations to be the most effective, with a mean effective size of 0.391 SD as compared to traditional instruction (Bayraktar, 2002). Akpan and Andre (2000) found that students who used a simulated frog dissection learned significantly more anatomy than those who performed actual dissections. Barnea and Dori (1999) concluded that chemistry students who used a computer-based molecular modeling simulation performed better than students using a traditional approach in three performance areas (spatial ability, understanding geometric and symbolic representations, and perception of scientific models). Huppert, Lomask, and Lazarowitz (2002) found that 10th-grade biology students using a computer simulation on the growth curve of microorganisms attained greater achievement on content-based objectives than those in a control group. In a comparison of a field trip experience to a computer simulation, Winn et al. (2006) found that while the field experience facilitated the contextualization of learning for students with little experience on the ocean, the simulation facilitated content acquisition by connecting what students learned from the simulation to other content they learned in class.

Other investigations have reported the success of computer simulations in supporting inquiry and reasoning skills. For example, Monaghan & Clement (1999) found that a computer simulation was effective in supporting inquiry by helping students test predictions and subsequently develop more accurate mental models of motion. Dori and Barak (2001) concluded that a combination of virtual and physical models used with inquiry style lessons supported learning and spatial understanding of molecular structure better than traditional lecture/demonstration methods. Geban, Askar, and Ozkan (1992) compared the effects of a computer-simulated experiment approach to chemistry instruction to those of a more conventional approach. They reported gains in chemistry knowledge and science process skills through use of the computer-simulated experiment approach.

A number of researchers have explored the potential of using computer simulations to facilitate conceptual change. In the first of these studies, Zietsman and Hewson (1986) explored the impact of a conceptual change-based computer simulation on high school and college students' misconceptions about the relationship between velocity and distance. The authors reported significant differences in pre- to posttest measures of students' conceptions and concluded that computer simulations can be especially well-suited for employing the conceptual change model. Brna (1987) investigated the use of the dynamics simulation, DYNLAB, to facilitate desired conceptual change for a small group of adolescent males. Pre- to posttest gains revealed that the DYNLAB simulation was successful in helping students recognize inconsistencies between their personal conceptions and scientific conceptions of the ways that forces interact with objects. More recently, Gorsky & Finegold (1992) explored the ability of a computer simulation about forces to promote conceptual change. The simulation was specifically designed to induce cognitive dissonance by simulating the consequences of students' alternative conceptions. Results indicated that the simulation was moderately successful in generating cognitive dissonance through direct experience with the animated discrepant events. Furthermore, those students who experienced cognitive dissonance went on to achieve scientific conceptions. Thus, experiencing the consequences of alternative conceptions through animated events may facilitate conceptual change. Zacharia and Anderson (2003) observed that interactive simulations improved physics students' abilities to make predictions and explain the results of mechanics, waves/optics, and thermal physics experiments. The authors concluded that simulations can facilitate conceptual change when properly integrated within a physics curriculum that emphasizes conceptual understanding.

In addition to using computer simulations as finished products, some researchers have investigated the efficacy of having students construct computer models as a means of improving their conceptions of space science concepts. In this regard, members of the *Virtual Solar System* project have conducted a series of investigations that involve students in constructing three-dimensional computer models in an undergraduate astronomy course (e.g., Barab, Hay, Barnett, & Keating, 2000; Barnett, Yamagata-Lynch, Keatng, Barab, & Hay, 2005). In the *Virtual Solar System* course, students used a simplified virtual reality modeling language (VRML) on desktop computers to build three-dimensional models of different aspects of the solar system. The course curriculum involved teams of students in completing three increasingly complex modeling projects designed to address astronomical phenomenon common to traditional introductory astronomy courses (e.g., the celestial sphere, lunar phases, and eclipses). These studies have demonstrated that building models of the solar system through the use of VRML software can support the development of deep understandings of astronomical phenomena.

Thus, a substantial body of research indicates that when designed and used properly, computer simulations can be effective tools for science instruction. Because simulations are simplified versions of the natural world, they have the potential to facilitate learning by focusing students' attention more directly on the targeted phenomena (de Jong & Van Joolingen, 1998). Additionally, good simulations allow students to visualize objects and processes that are normally beyond perception and in some cases to manipulate variables that are normally beyond the users' control. It therefore follows that at least in some cases, computer simulations can facilitate learning more effectively than direct experience (Winn et al., 2006).

Despite these potential advantages, some science educators and researchers have cautioned that the use of educational technology can exacerbate problems in teaching and learning. For example, Marshall and Young (2006) found that secondary preservice teachers failed to take advantage of many features of a physics simulation that could have made it advantageous over an equivalent hands-on activity, and that the simulation hindered the students' testing and refinement of tentative theories. In a study on the impact of technology on inquiry in a sixth grade classroom, Waight & Abd-El-Khalick (2007) concluded that technology can actually restrict the enactment of inquiry by limiting student discourse and engagement in scientific thinking. Others have cautioned that technology use can hinder deep reflection and understanding of complex science content (Olson & Clough, 2001). Lending support to these concerns, two early studies report lower achievement for students using computer simulations than for those who experienced traditional instruction (Bourque & Carlson, 1987; Kinzer, Sherwood, & Loofbourrow, 1989). Additionally, a review of literature from the 1970s and 1980s related to the use of computer simulations in science instruction revealed no significant positive effects on student achievement (Kulik, 1994). Thus, it is too early to draw definitive conclusions about the effectiveness of computer simulations. Additional research is needed that explores the efficacy of simulations (like planetarium software) to promote scientific conceptions of complex phenomena.

Theoretical Framework

The theoretical framework underlying the design and implementation of this study comes from constructivist and conceptual change theories. Constructivism posits the notion that learners create or construct new knowledge (von Glasersfeld, 1984). As learners access information through their senses, the construction of new knowledge comes from an interaction between their existing knowledge and new experiences and ideas with which they come in contact in the natural world and their culture (Richardson, 2003). Because constructivism takes into account learners' existing knowledge, the understandings that students bring to the classroom takes on an important role in the learning process. Learning takes place as new information is related to the preexisting knowledge schema. Since students' ideas can be at odds with scientifically accepted norms (Driver & Oldham, 1986), preconceptions are often considered to be misconceptions or alternative conceptions (Bodner, 1986; Hewson & Hewson, 1983; Posner, Strike, Hewson, & Gertzog, 1982).

For more than two decades researchers have been interested in students' alternative conceptions. Conceptual change theory evolved from this alternative conceptions research (Posner et al., 1982). Conceptual change learning involves actively generating and testing alternative propositions to explain observed phenomena (Tyson, Venville, Harrison, & Treagust, 1997). The present investigation is based upon foundational conceptual change literature in science education, (Beeth, 1998a, 1998b; Driver & Oldham, 1986; Hewson & Hewson, 1988; Strike & Posner, 1992) and more heavily on recent literature reflecting a conceptual development perspective (Carey, 1985; Vosniadou, 1991, 1999, 2003; Vosniadou & Brewer, 1994; Vosniadou, Skopeliti, & Ikospentaki, 2004). Vosniadou's work, which has been informed by several studies addressing earth and astronomy concepts, appears to be particularly relevant in thinking about conceptual change in the context of the present study. The following perspectives, which served to guide our work, draw heavily on the conceptual development perspective articulated by Vosniadou and other scholars.

(1) Alternative conceptions may form prior to formalized instruction (Vosniadou, 1999, 2002).
(2) Alternative conceptions can be organized, coherent, and highly resistant to change if they are associated with entrenched ideas (Vosniadou, 1994a, 1999). These existing conceptual structures, which are often at odds with scientifically accepted norms, may facilitate or hinder learning (Vosniadou, 1999).
(3) Conceptual change may be time intensive and gradual, occurring with experiences over extended periods of time (Vosniadou, 1994a, 1999, 2002; Vosniadou & Brewer, 1992).
(4) Conceptual change may occur through enriching existing conceptual structures or radically reorganizing existing structures (Stafylidou & Vosniadou, 2004; Vosniadou, 1994a).
(5) Misconceptions may form as students try to integrate new information into their existing conceptions (Stafylidou & Vosniadou, 2004). This integration and the resulting misconceptions may result from formalized instruction as well as informal daily experiences (Vosniadou, 2002).
(6) Conceptual change involves more than cognitive aspects and may be influenced by beliefs, motivation, learning attitudes, and sociocultural contexts (Ivarsson, Schoultz, & Saljo, 2002; Linnenbrink & Pintrich, 2002; Pintrich, 1999; Vosniadou, 2003).
(7) For some science concepts, the frequency with which specific alternative conceptions are held is consistent across diverse populations (i.e., age, abilities, and nationalities; Samarapungavan, Vosniadou, & Brewer, 1996; Trundle et al., 2002; Vosniadou, 1994b).

Purpose of the Study

The purpose of this study was to describe changes in conceptual understandings of preservice elementary teachers on standards-based lunar concepts as a result of inquiry instruction based on the computer-based planetarium program, *Starry Night Backyard*. The following research questions guided the investigation:

1. What are preservice early childhood teachers' preinstruction conceptions of moon phases?
2. How do the preservice teachers' conceptions of moon phases change as a result of an inquiry-based instructional intervention using a computer simulation?
3. Can experience with a computer simulation effectively substitute for direct observations within a conceptual change framework?

Methods

Participants

The preservice teachers recruited to participate in this study were graduate students enrolled in a Masters of Education initial licensure program for early childhood education (Pre-K-3) at a major Midwestern research university. A total of 50 of the 59 recruited students agreed to participate. They were enrolled in a science methods course, which was part of the early childhood education program. Most of the 50 participants were Caucasian females (41, 82%). Other participants included four males (three Caucasians, and one African American), three African-American females, and two Asian American females. The number of college science credits that participants had completed before entering the study ranged from 5 to 30 quarter hours, with a mean of 11.3. Thirteen participants had completed one astronomy course, and three had completed two astronomy courses.

Instructional Intervention

The instructional intervention integrated the planetarium software *Starry Night Backyard* with instruction on moon phases from *Physics by Inquiry* by McDermott (1996). In regard to the general inquiry-based approach and to specific instructional activities, the intervention was identical to that of previous investigations by Trundle et al. (2002, 2004, 2006, 2007a,b). What differed in the present investigation was that preservice teachers' moon observations were collected from the *Starry Night Backyard* software rather than from actual observations of the moon.

Key aspects of the instructional intervention were informed by Vosniadou's conceptual development perspective. First, the methods instructor recognized that her preservice early childhood teachers were likely to possess coherent alternative conceptions that could be highly resistant to change. Thus, she elicited her students' ideas about moon phases prior to instruction, and had them reflect on their understandings of moon phases at key points during the 4 weeks of moon phase activities. The extensive nature of the moon phase instruction reflected the instructor's belief that changing her students' alternative conceptions would be a gradual process facilitated by participation in a variety of activities designed to challenge their alternative conceptions and help them build a foundation of experiences on which to build conceptions more aligned with the scientific view. To this end, the instruction was divided into three parts: (1) gathering, recording, and sharing moon data, (2) analyzing moon data by looking for patterns in the data, and (3) modeling the cause of moon phases.

First, the participants were taught how to gather, record, and share moon observations. This involved teaching the preservice teachers basic controls of the *Starry Night Backyard* software, including setting the date, time, observation location, and orienting the view to cardinal directions (i.e., north, south, east, and west). For more information on the use and features of *Starry Night Backyard* software, see Trundle and Bell (2003). Next, the methods instructor explained and modeled how to gather and record observational moon data. The participants then worked in pairs at computer stations to use the *Starry Night Backyard* software to make daily moon observations by recording a drawing of the shape of the moon, the time of the observation, the angular separation between the sun and moon, and the direction they looked to see the moon. Moon observations were recorded individually by each participant on a calendar, which had a circle for each day where the participants sketched the shape of the moon.

The participants recorded daily moon observations for 9 weeks. Having students collect moon observation data for an extended period of time is recommended by the *Physics by Inquiry* curriculum (McDermott, 1996), and is consistent with previous research on instructional interventions designed to promote scientific conceptions of moon phases (e.g., Abell et al., 2002; Trundle et al., 2002). More specifically, collecting 9 weeks of data provided students with two full lunar cycles from which to draw conclusions and test predictions. Using *Starry Night Backyard*, participants were able to collect the 63 observations during portions of only 4 weekly class sessions. Each of these weekly class sessions included data-sharing in which selected participants replicated their sketches on the chalkboard and recorded the dates, times, angular separation, and directions for the observations. Then the participants looked for and discussed any anomalies in the shared data.

After the 4-week period of sharing data, the participants devoted two class periods (approximately 4 total hours) to the analysis of their data by looking for and discussing patterns and then modeling the cause of moon phases. This part of the instruction was divided into five major sections which included the following topics: (1) identifying observable patterns, (2) determining the length of the cycle, (3) sequencing the observed shapes, (4) applying new concepts and scientific labels, and (5) modeling the cause of moon phases. Since the analysis of the moon data portion of the instruction was identical to the instruction used in other research which is thoroughly described in published form and available elsewhere (Trundle et al., 2002, 2004, 2006, 2007a,b), the instruction is summarized briefly here in Table 2.

The total amount of in-class instructional time devoted to the study of moon phases was approximately 6 hours, including the time required for in-class data gathering using the *Starry Night Backyard* software. Previous research (Trundle et al., 2002, 2004, 2006, 2007a,b) has shown that similar instruction using actual observations of the moon was very effective in helping preservice early childhood teachers and students construct a scientific understanding of the shape and sequence and cause of moon phases. However, this instruction is labor-intensive, requiring 8 hours of in-class instructional time, plus many additional hours for students to record data over the 9-week observation period. The instructional intervention of the present study differed from previous work by replacing actual observations of the moon with similar observations using the *Starry Night Backyard* software, reducing the in-class instructional time by 2 hours, and eliminating hours of after-class observations.

Data Collection

To answer the research questions, the study incorporated both qualitative and quantitative data in a single case pretest–posttest design. The goal was to provide rich, detailed information about the participants' conceptions of moon phases without constraining their responses to

Table 2
Summary of instructional activities.

Targeted Concepts	Summary of Activities
Identifying observable patterns	Identify and describe patterns Describe rate of change (i.e., gradual or abrupt) Draw an observed sequence of moon shapes Identify when the sky was clear but the moon could not be observed
Determining the length of the cycle	Number data from day 1 to day 63 Select a distinctive shape List the number of the day that the shape first appeared List the number of the second and third days when the shape reappeared Repeat with three additional shapes Estimate how much time passed before each shape reappeared
Sequencing the observed shapes	Sequence a series of drawings of eight representative phases in the pattern observed
Applying new concepts and scientific labels	Use the scientific term ''new moon'' to describe when the moon could not be observed during the moon cycle Use the scientific term ''synodic period'' to describe the time interval from new moon to full moon and back to new moon Apply scientific labels (e.g., waxing gibbous) to each shape
Modeling the cause of moon phases	Participate in a psychomotor modeling activity by first darkening a room Place a bright, exposed light bulb at eye level to represent the sun Use a Styrofoam ball as a model for the moon Hold the ball in front of body at arm's length The student's head is the earth Move the ball around their heads Note the appearance of the lit portion of the ball Determine how much of the moon is lit at any one time Use the models to reproduce all the phases in the order they were observed Write and orally explain their understandings of the causes of moon phases

predetermined categories. A variety of data sources were used to characterize participants' conceptions of lunar phases and their cause, including drawings, interviews, and a lunar shapes card sort. The structured interview protocol used in the current study was developed and used in previous research (Trundle et al., 2002, 2004, 2006, 2007a,b) and occurred immediately before (pre-) and 3 weeks after (post-) the instructional intervention. During the videotape recorded interviews, participants completed six tasks designed to assess their understandings of three targeted conceptions of moon phases:

- the observable shapes of the moon (Task 1),
- how these shapes change over the course of a month (Tasks 2, 3, and 6),
- the cause of the changes in the shapes of the moon (Tasks 4 and 5).

For Task 1, each participant was asked to draw all of the shapes of the moon that they expected to see (pre) or had seen (post) over the course of the observation period. For Task 2, participants were asked to predict whether they thought that the moon shapes would change in a predictable pattern (pre) or to describe whether they had changed in a predictable pattern (post). Next, the participants were asked to sequence the moon shapes (Task 3, pre and post), and to explain what they thought caused the different moon shapes (Task 4, pre and post). Additionally, participants were asked to use three-dimensional models of the earth, moon and sun to demonstrate their ideas in conjunction with their verbal explanations (Task 5, pre and post). Finally, participants were asked to complete a card sorting activity in which they placed representations of the eight primary lunar phases in the proper sequences (Task 6, pre and post). As participants completed each task, the interviewer probed to investigate the participants' conceptual understanding rather than just accepting initial responses.

Data Analysis

The constant comparative method was used to analyze data (as per Strauss & Corbin, 1994). The data analysis system used in this study was developed by Trundle et al. (2002, 2004, 2006, 2007a,b). In moon studies with preservice teachers and children, Trundle et al. used previous research (Callison & Wright, 1993; Stahly, Krockover, & Shepardson, 1999; Targan, 1988) to identify criteria to describe a scientific understanding and possible alternative conceptions participants might have, from which a "partial framework" (Glaser & Strauss, 1967, p. 45) was developed for analysis. 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. In the current study, the researchers used these coding sheets and the coding system for each interview. Participants' pre- and postinstruction coding sheets were compared to scientific views of patterns and causes of moon phases to assess attainment of target understandings.

Prior to analysis of the entire data set, the two authors and a graduate student who helped with the data analysis independently analyzed and coded a random sample of seven data sets. Comparison of the three separate analyses indicated that the three researchers achieved inter-rater agreement of better than 90%.

The data analysis process produced detailed profiles of each participant's pre- and postinstruction conceptual understanding of lunar concepts. The researchers then compared the pre- and postinstructional profiles of each participant to accepted scientific norms as a measure of effectiveness of the technology-enhanced instructional intervention.

Results

Shapes

Results of analyzing and coding the participants' drawings are summarized in Table 3. For the preinstruction administration of Task 1, participants were told that they would be making moon observations for the next 9 weeks, and they were asked to draw all the moon phases they expected to see. For this discussion, we exclude the results for the full and new moon because the full moon was essentially given to the participants in the prompt. Thus, it is not surprising that all of the participants included a full moon among their preinstruction drawings. Since the participants were asked to draw all the shapes they expected to see, it is also reasonable to expect them to exclude the new moon from their drawings because we are unable to visually observe the new moon (except during a solar eclipse).

Excluding the full moon, the waning crescent was the most commonly drawn shape before instruction. Most participants (41 of 50, 82.0%) included a waning crescent, and more than half included a waning gibbous (30 of 50, 60.0%) and a third quarter (26 of 50, 52.0%). Half or less of

Table 3
Frequencies of participants who included specific moon phases in Task 1 drawings.

Moon Phases	Preinstruction Assessment		Postinstruction Assessment	
	Scientific	Non-Scientific	Scientific	Non-Scientific
Waning gibbous	6	24	41	8
Third quarter	15	11	49	0
Waning crescent	8	33	47	2
Waxing crescent	4	19	48	2
First quarter	13	2	50	0
Waxing gibbous	7	9	39	10

the participants, however, indicated that they expected to see any of the other phases, including the waxing crescent, first quarter, and waxing gibbous moons. Additionally, the difference in the number of participants who completed waning versus waxing phase drawings is striking. Specifically for Task 1, there were 97 instances where participants drew waning phases prior to instruction, compared to only 54 instances of drawing waxing phases.

In addition to omitting many observable shapes, nearly all participants (48 of 50, or 96.0%) included at least one non-scientific shape among their preinstruction drawings. Waxing and waning crescent phases were considered to be non-scientific if they were drawn either as over- or under-articulated. Non-scientific first and third quarter moons were drawn like a curved "half moon," consistent with a partial lunar eclipse. Similarly, non-scientific gibbous moons also were drawn as a partial lunar eclipse. Figure 1 presents Meg's preinstructional drawings of moon shapes, indicating both under-articulated crescent moons and "partial eclipse" gibbous moons. Before instruction there were a total of 98 instances for Task 1 in which participants drew moons that were of non-scientific shapes. Thus, 64.9% (98 of 151) of all preinstruction attempts to draw moon phases were non-scientific.

The most negative preinstruction result for Task 1 was for the quarter and gibbous moons. Fewer participants drew quarter moons compared to all other phases, with 31.7% (13 of 41) of

Figure 1. Meg's preintruction drawings of moon phases, indicating alternative shapes for gibbous and crescent moon phases.

these drawings being non-scientific. While participants drew more gibbous moons (46), more of their attempts were non-scientific 71.7% (33 of 46 gibbous moon drawings).

Of the 16 participants who had previously completed at least one astronomy course, only 1 (6.3%) drew scientifically accurate moon shapes prior to instruction. Even though all five of the shapes she drew were coded as being accurately represented, she omitted both the waxing and waning gibbous moons altogether and she was unable to organize the shapes into accurate waxing and waning sequences. All of the other 15 participants who had completed course work in astronomy included alternative shapes among their drawings, with a range of 2–12 and a mean of 4.8 non-scientific shapes per person. This mean was actually higher than for the larger group who had not taking any astronomy courses (mean = 3.8).

The postinstruction results in Table 3 reveal dramatic improvement over preinstruction results. Almost all of the participants 98.0% (49 of 50) attempted to draw each of the eight expected phases in response to Task 1. Further, 39–50 of the participants recorded scientific drawings for each particular phase. Figure 2 presents Meg's postintructional drawing of moon shapes. Note her inclusion of all eight major shapes, as well as the lack of any alternative shapes.

Once again, it was the gibbous phases that gave the participants the most difficulty. Even so, only 18.4% (18 of 98) total gibbous drawings were non-scientific, compared to 71.7% (33 of 46) gibbous drawings prior to instruction. The overall improvement over preinstruction results was just as dramatic. Before instruction, only two participants (4.0%) drew all of their moon phases with scientific shapes on Task 1. After instruction, 40 participants (80.0%) accurately accomplished the task.

Sequences

In Task 2 participants were asked whether they would expect different moon phases to appear in a predictable sequence. For Task 3, those participants who indicated they expected the moon phases to appear in a predictable sequence were asked to draw the phases in the pattern they expected to observe.

Prior to instruction, all 50 participants expected the moon phases to appear in a predictable sequence (Table 4). Preinstruction results for Task 3 indicated that only 29 of the 44 (65.9%) participants who attempted to draw the waning sequence consistently used scientific representations. The result was even poorer for a waxing sequence, with only 12 of 31 (38.7%) participants' attempts being classified as scientific. The most common alternative sequence involved drawing waning moon shapes in a waxing moon sequence (Figure 3). Overall, only 9 (18.0%) participants were able to draw accurate representations of both the waxing and waning

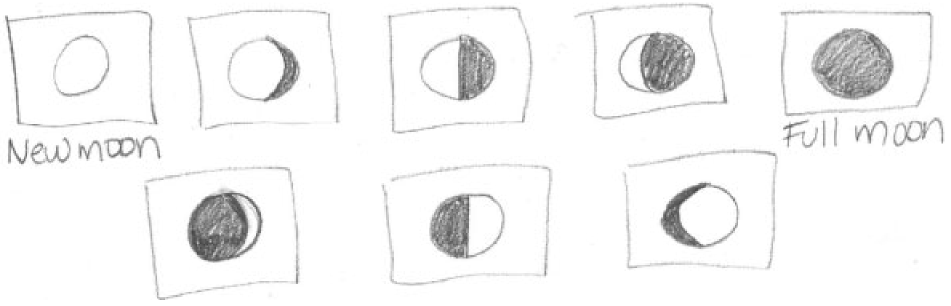

Figure 2. Meg's postinstruction drawings of moon phases. Note that she has chosen to represent the lit portion of the moon as shaded in these drawings.

Table 4
Frequencies of participants who included scientific and non-scientific sequencing of preinstruction and postinstruction drawings of moon phases.

Sequence	Preinstruction		Postinstruction	
	Scientific	Non-Scientific	Scientific	Non-Scientific
Task 2: predictable sequence?	50 (yes)	0 (no)	50 (yes)	0 (no)
Task 3: draw expected sequence of phases				
Moon wanes	29	15	49	1
Moon waxes	12	19	50	0
Moon wanes and waxes	9	41	49	1

sequences. Note that participants did not have to include all waxing and waning phases listed in Table 1 in order to be classified as scientific. Enough drawings did have to be included, however, to show a waxing or waning phenomenon.

Of the 16 participants who had previously completed at least one astronomy course, 12 (75.0%) attempted to represent both the waxing and waning sequences before instruction. Only 6 (37.5%) were able to organize the shapes into scientifically accurate waxing and waning sequences, compared to 18.2% of the larger group of participants who had not completed any

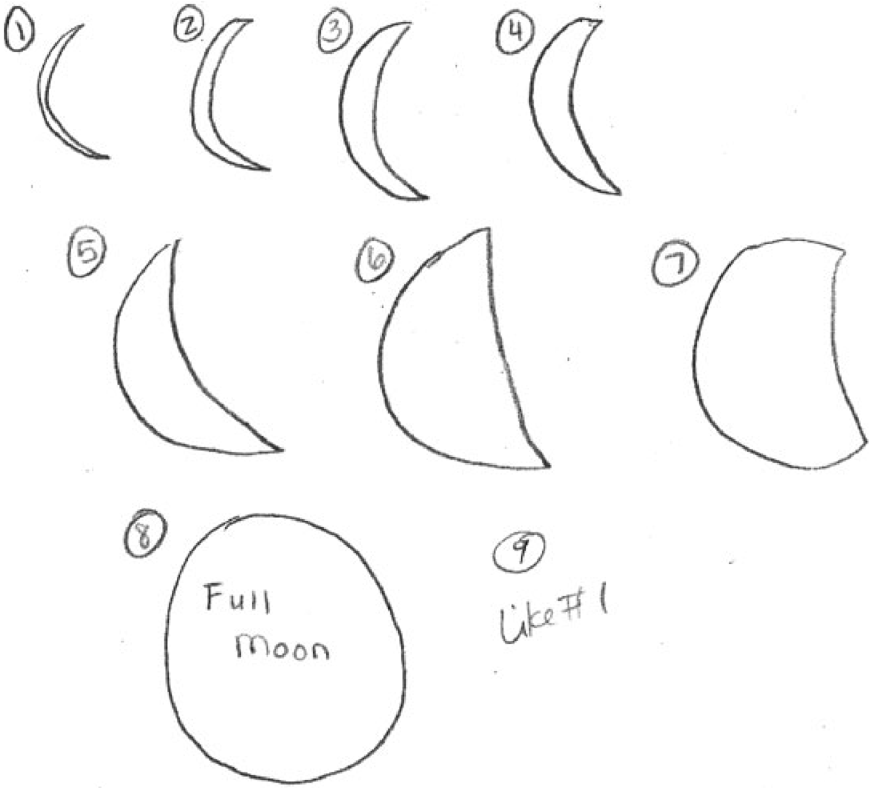

Figure 3. Nan's preintruction drawings of moon sequence, indicating alternative shapes and sequence (waning moon shapes progressing in a waxing sequence). Note the absence of any waxing moon shapes.

astronomy courses. Thus, the participants who had completed at least one astronomy course were more likely to attempt to represent both the waxing and waning sequences than those who had not, and a higher percentage were able to scientifically represent moon phase sequences.

Postinstruction responses to Tasks 2 and 3 indicated substantial gains when compared to the preinstruction results. As was true for the preinstruction assessment, all participants expected the moon phases to appear in a predictable sequence. For Task 3, 49 (98.0%) of the participants' waning sequences were classified as scientific, and all 50 participants' waxing sequences were judged to be scientific representations. All of the participants attempted to draw both a waxing and waning sequence, with 49 (98%) of these sequences judged scientific. Nan's postinstruction representation of the moon phase sequence is provided in Figure 4.

Summary of Shape and Sequence Results

Prior to instruction, a large majority of the preservice early childhood teacher participants included alternative, non-scientific phases in their moon drawings (48 of 50, 96.0%). Only 2 participants (4.0%) drew scientific moon phases (Table 5). Before instruction, most participants' knowledge of the regularly recurring pattern of moon phases was described as non-scientific (41 of 50, 82.0%), and only 9 participants (18.0%) accurately drew both the waning and waxing moon phase sequences. None of the participants (including those who had completed one or more college-level astronomy courses) were able to draw both scientific phases and scientific sequences.

After instruction, a large majority of participants (80.0%) drew scientific moon phases, and moon phase sequences (98.0%). Also, participants' ability to draw both scientific moon phases and sequences (80.0%) improved dramatically. These findings indicate that the instructional intervention helped the preservice early childhood teachers to develop foundational knowledge for understanding the causes of moon phases.

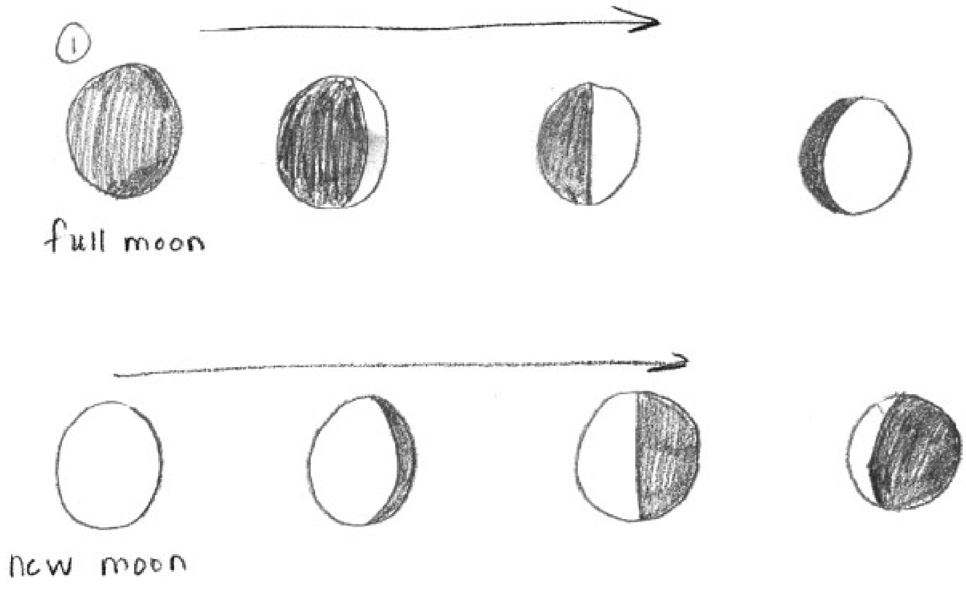

Figure 4. Nan's postinstruction representation of moon phase sequence. Note that she has chosen to represent the lit portion of the moon as shaded in these drawings.

Table 5
Gains from pretest to posttest for drawings of shapes and sequences.

Participants' Drawings Consisted of:	Pretest	Posttest	Gain (Posttest−Pretest)
Scientific moon phases	2 (4.0%)	40 (80.0%)	38 (76.0%)
Scientific waning and waxing sequences	9 (18.0%)	49 (98.0%)	40 (80.0%)
Scientific phases and sequences	0 (0.0%)	40 (80.0%)	40 (80.0%)

Cause of Moon Phases

Structured interviews were the main source of data used to characterize participants' conceptions of the causes of moon phases. During the interviews, participants were asked to explain what they thought caused moon phases, and were encouraged to use three-dimensional models to demonstrate their ideas in conjunction with their verbal explanations. Additionally, the interviewer used probing questions to delve deeper into the participants' conceptual understandings.

This in-depth assessment of the participants' preinstruction conceptions of the causes of moon phases revealed the categories of conceptual understandings listed in Table 6. All but one of the participants' preinstruction responses (49 or 98.0%) indicated that they held alternative conceptual understandings or alternative fragments. Only one participant met the criteria for a scientific fragment, and none met the four criteria required for a scientific conception. By far, the most frequently identified alternative conception (22 of 50, 44.0%) was that the earth's shadow causes the phases of the moon (eclipse). The following excerpt from Pam's (pseudonym) interview transcript is provided as representative of participants' expression of the alternative eclipse conception.

> Researcher: You did some drawings of moon shapes earlier. What would make the moon appear like your different drawings?
> Pam: Because the earth is covering up part of it so that only part of the moon is getting the sunlight to reflect **[Alt Eclipse]**. And so if the sun was right here [*holding her left fist in front of her on her left side*] and the moon was just peeking out right here [*holding up her right hand in front of her near her left hand*] it would look like a little sliver.
> Researcher: OK. You said the moon is just peeking out. Peeking out from where?
> Pam: [Laughing] Yes, just peeking out from behind the earth **[Alt Eclipse]**. OK, like if the sun is over here [*using her right hand to point out to her left*] and the earth is here [*holding up her left fist in front of her left side*] and the moon is back here [*holding up her right fist behind her left fist and closer to her body than her left fist*] it would be just a little sliver if it was just peeking but if it was all out [*moving her right fist to her right and forward and out from behind her left fist*] like here it would be a full moon.
> Researcher: Why would that be a full moon?
> Pam: Because the earth isn't blocking any of the sun's light **[Alt Eclipse]**.

In addition to the alternative conceptions listed in Table 6, preinstruction interviews indicated that most of the participants (34 of 50, or 68.0%) did not understand that the moon orbits the earth. Five of these participants indicated that the moon is stationary and always remains in the same place in space, three used a geocentric model with the sun and moon orbiting around the earth, and four indicated that the earth and moon orbit around the sun independently of each other, allowing the sun to come between the earth and moon.

Table 6
Frequencies of participants who expressed specific preinstruction conceptions of the causes of moon phases.

Type of Conceptual Understandings	Criteria and [Codes]	Participants Expressing This Conception
Scientific	All four scientific criteria included: Half of the moon is illuminated by the sun [Sci Half] The portion of the illuminated half seen from earth varies over time [Sci See] The relative positions of the earth, sun, and moon determine the portion of the lighted half seen from earth [Sci EMS] The moon orbits earth [Sci Orb]	0 (0%)
Scientific with alternative fragment	Met all four scientific criteria, but also indicated held one of the alternative fragments listed below	0 (0%)
Scientific fragments	Included a subset but not all of the four scientific criteria	1 (2.0%)
Alternative eclipse	The earth's shadow causes the moon phases [Alt Eclipse]	22 (44.0%)
Alternative earth's rotation	The earth's rotation on its axis causes the moon phases [Alt Rot]	8 (16.0%)
Alternative heliocentric	Moon orbits the sun but not earth. In other words, the moon and earth orbit the sun independently of each other. When the sun gets between the earth and moon, the moon is in the new moon phase [Alt Helio]	4 (8.0%)
Alternative geocentric	Sun and moon orbit the earth, causing moon phases [Alt Geocentric]	3 (6.0%)
Alternative clouds	Cloud cover causes moon phases [Alt Clouds]	1 (2.0%)
Alternative planet	Planet's (other than earth) shadow on moon causes moon phases [Alt Planets]	1 (2.0%)
Alternative distance between the moon and sun	Varying distance between sun and moon. When moon is closer to sun the moon is full. When it is further away from the sun, the moon is in the new moon phase [Alt Distance]	1 (2.0%)
Alternative fragments	Included a subset or subsets of alternative conceptual understandings	9 (18.0%)

We include the interview responses of Quin as representative of the alternative geocentric conception of moon phases. Like other participants who held a geocentric conception of the cause of moon phases, Quin's use of the models and her verbal responses indicated that she believed that the sun orbits the earth. On the other hand, Quin's views were unique in that she also believed that the moon remains at a stationary point in space and does not move relative to the earth and sun. It is also interesting to note that Quin seemed to have a scientific understanding about how the spatial relationship between the positions of the earth, moon, and sun play a role in causing moon phases. Based on her understanding that the relative positions of earth, sun, and moon determine the part of the moon we see, Quin was able to accurately position the models so that the moons would appear like the phases targeted in the interview (e.g., full moon, new moon, waning crescent).

> Researcher: You did some drawing of the moon phases you expect to see. Now I want you to explain to me what you think causes moon phases.
> Quin: It's due to the sun's rotation around the earth **[Alt Geocentric]**. Like the sun goes around us, orbiting around us **[Alt Geocentric]**, and as that happens we see different moon phases.
> Researcher: OK. The sun is going around the earth. How is that causing moon phases?
> Quin: While the sun is rotating around the earth **[Alt Geocentric]** that affects how much light is reflected off the moon. The sun's rays reflections determine what moon phase we see, how much of the moon we see.
> Researcher: OK. Tell me how that would work for one of the phases you drew here.
> Quin: OK. Like with the full moon, that's the most reflection, we get the most light reflection. Then we lose some of the brightness and we see less and less of the moon.
> Researcher: And why do we see less and less of the moon?
> Quin: The sun is moving further away from the moon as it orbits around the earth **[Alt Geocentric]**.
> Researcher: OK. You mentioned the sun, moon, and the earth and I have models of these that I want you to use to show me and explain to me what causes moon phases.
> Quin: [*moving the sun component away from her body and toward the camera, moving the earth component toward her so that the sun and earth are in a straight line, and holding the moon component in her left hand, close to her body and to her left side. The models are arranged at approximately a 135 degree angle at a waxing gibbous position*]. OK. My understanding is that the moon is at a fixed point here, but I'm not sure where it would be. It's just at a stationary point in our galaxy or wherever **[Alt Moon Orbit]**. And the earth is here [*pointing to the earth*] and the sun would go around [*holding the sun component in her right hand and moving it around the earth component in a counterclockwise motion for three orbits*] **[Alt Geocentric]** and during, it's the relationship between the moon and sun that determines what the moon looks like **[Sci EMS]**. As the sun orbits the earth it changes what we see **[Alt Geocentric]**.

Of the 16 participants who had previously completed at least one astronomy course, none held a scientific understanding of the cause of moon phases before instruction. The frequencies of the alternative conceptions expressed by this subgroup were similar to those of the larger group. For example, most believed that moon phases were caused by the earth's shadow (11 of 16, or 68.8%). More than half of the participants (9 of 16, 56.3%) who had completed an astronomy course did not understand that the moon orbits the earth. One of the 16 subscribed to a geocentric model where the sun and moon orbit the earth while another indicated that she believed the moon always stayed in one place and did not move.

After completing the inquiry-based instructional intervention with *Starry Night Backyard*, most of the participants (41 of 50, 82%) were able to articulate scientific explanations for the cause of moon phases (Table 7). Excerpts from Quin's postinstruction interview transcript are provided below as a representative sample of an articulation of a scientific conception of the causes of moon phases. Note the improvement in Quin's achievement of all four targeted components of the scientific conception of moon phases over her preinstruction responses presented above.

> Researcher: Pick a different moon phase to tell me how that would work.
> Quin: Well, a waning gibbous would be the moon is moving from this position here [*using her right fist to represent the moon, and moving it slightly counterclockwise around her other fist, which represents the earth*], it's moving around so we see a little bit less of the moon because the direction of the sunlight is at a different angle. It all has to do with the angle from the sun, earth, and moon **[SciEMS]**.

Table 7
Frequencies of types of conceptual understanding of cause of moon phases.

Type of Conceptual Understanding	Before Instruction Frequency (%)	3 Weeks After Instruction Frequency (%)
Scientific	0 (0.0%)	41 (82.0%)
Scientific with alternative fragment	0 (0.0%)	1 (2.0%)
Scientific fragments	1 (2.0%)	0 (0.0%)
Alternative	40 (80.0%)	0 (0.0%)
Alternative fragments	8 (16.0%)	8 (16.0%)

> Researcher: Most people use their hands when they answer these questions. So I have models of all the things you were talking about [sun, earth, and moon]. I want you to use these models to show me and explain to me what causes moon phases.
> Quin: [*Arranges the model components so that the sun and earth are in a straight line, and holds the moon component in her right hand with the earth between the sun and moon. The models are arranged at approximately 180 degrees at a full moon position*.] As the moon travels around **[SciOrb]** we see different parts of it. [*Moving the moon in a counterclockwise direction around the earth*]. It's not a 180 degree angle like it was for the full moon and as we move, less of it is visible. As we move over here it's a 90 degree angle which is when we see a quarter moon **[SciEMS]** . . .. As we go around like this, this would be a new moon [*Holding the moon between the earth and the sun]* because, the moon is still being lit [*Pointing at the half of the moon facing the sun*], but the side that is lit is the side that we can't see because we can't obviously see through the moon or see the other side . . ..
> Researcher: Why is that a new moon?
> Quin: The sun is hitting this part of the moon [*points to the half that is not facing the earth*], which is not visible to us. So, although half of it is being lit **[SciHaf]**, this part right here [*Pointing to the half that is facing earth*], what we can see **[SciSee]**, is not being illuminated.

While having the preservice teachers gain scientific understandings of the target concepts was the ultimate instructional goal, we considered progress toward a scientific understanding to be important, as well. An additional participant was classified as having a scientific understanding, but holding on to an alternative fragment. Thus, the total number of participants who gained (or progressed toward) scientific conceptions of moon phases was 42 out of 50 (84%). Only 8 participants (16%) were identified as holding alternative fragments despite having participated in the inquiry-based instruction with *Starry Night Backyard*.

Table 8 presents a summary of the investigation results. Participants' pre- to postinstruction gains were substantial, indicating that the majority had experienced desired conceptual change for each of the targeted moon phase concepts.

A non-parametric statistical test was used to support the qualitative comparisons by examining the numbers of participants who shifted in content knowledge from alternative to scientific drawings from pre- to the posttest. The Wilcoxon Signed Ranks Test examined the paired dichotomous categories for all possible shifts in accuracy (e.g., drawing alternative moon shapes on the pretest and shifting to scientific shapes on the posttest or drawing alternative moon shapes on both the pretest and posttest with no shift). Significantly more preservice teachers shifted from drawing alternative shapes on the pretest to drawing scientific shapes on the posttest than any other possibility ($z = 6.164$, $p < .001$). Results for the sequences were similar in that significantly more

Table 8
Participants' responses coded as scientific.

Targeted Moon Phase Conceptions	Pretest (%)	Posttest (%)	Gain (Post–Pre) (%)
Scientific moon phase drawings	4.0	80.0	76.0
Scientific waning and waxing sequence drawings	18.0	98.0	80.0
Both scientific phases *and* sequence drawings	0.0	80.0	80.0
Scientific cause of moon phases interview responses	0.0	82.0	82.0

participants shifted from drawing alternative waxing and waning sequences on the pretest to drawing scientific sequences on the posttest ($z = 6.325$, $p < .001$). Also, significantly more preservice teachers shifted from drawing both alternative shapes and sequences on the pretest to drawing both scientific shapes and sequences after instruction ($z = 6.325$, $p < .001$). The Wilcoxon Signed Ranks Test also was used to examine the number of participants who shifted in their conceptual understanding of the cause of moon phases. These results indicated that significantly more participants shifted from alternative understandings before instruction to a scientific understanding on the posttest ($z = 6.403$, $p < .001$).

The overall goal of the instruction was to support the participants' development of content knowledge of the patterns of shapes and sequences of moon phases and conceptual understanding of the cause of moon phases. Thus, the Wilcoxon Signed Ranks Test was again used to examine the number of participants who shifted in their knowledge of moon shapes and sequences and understanding of the cause of moon phases. The results indicated that significantly more participants shifted from drawing alternative shapes and sequences while using alternative explanations for the cause of moon phases on the pretest to drawing scientific shapes and sequences with a scientific explanation of the cause of moon phases on the posttest than any other possibility ($z = 5.657$, $p < .001$). The overall results of the non-parametric statistical tests were consistent with the qualitative analyses: the participants made substantial gains in their understandings of scientific shapes, sequence, and causes of moon phases over the course of the investigation.

Discussion and Implications

Prior to the instructional intervention, none of the preservice teacher participants in this investigation held complete scientific understandings of the patterns and causes of moon phases. Their conceptions of observable moon shapes were incomplete and typically included non-scientific shapes consistent with partial lunar eclipses. While all of the participants understood that moon phases progress in a predictable pattern, few were able to adequately describe the moon's waxing and waning sequences. None of the participants expressed scientific explanations of moon phases, with most attributing the cause of moon phases inaccurately to the earth's shadow. Taken as a whole, these results demonstrate that prior to the instructional intervention, this group of preservice teachers did not possess scientific understandings of (1) the observable moon phases, (2) the recurring waxing and waning pattern of change in the phases, or (3) the causes of moon phases, as specified in the *National Science Education Standards*. Clearly, these preservice teachers entered the early childhood science methods course without the scientific conceptions necessary to teach effectively about moon phases. This conclusion is true for all participants, even though almost a third had completed at least one college-level astronomy course.

These preinstruction results are well-aligned with the findings of a number of previous investigations into preservice elementary teachers' and students' conceptions of moon phases. For example, Trundle et al. (2002, 2004, 2006, 2007a,b) have found that prior to explicit conceptual change-informed instruction, preservice teachers and students typically draw non-scientific shapes consistent with the view that moon phases are caused by the earth's shadow. Additionally, they appear unfamiliar with waxing moon shapes, which are under-represented in their drawings. Many are not able to draw a scientific sequence of phases. Some do not understand that the moon orbits the earth, and most believe that the phases are caused by the moon passing through the earth's shadow, which occurs only during an eclipse. The consistency of these findings to those of the present investigation provides a strong basis for predicting that many preservice teachers in other teacher education programs hold non-scientific conceptions of the shapes, sequence, and causes of moon phases, as well.

Perhaps even more disquieting is the present study's finding that the participants who completed one or more astronomy courses did not fair any better on the preassessments of moon phase conceptions. The results of this investigation should serve to caution those involved in science teacher preparation that completing college-level astronomy course work does not guarantee the development of the scientific conceptions necessary to teach abstract astronomical concepts.

Fortunately, the technology-enhanced inquiry instruction was effective in promoting scientific knowledge of moon shapes and sequences, as well as scientific understanding of the cause of moon phases. Achievement gains were in the order of 80% for all targeted conceptions. Furthermore, the results of the technology-enhanced inquiry instruction were as good as or better than those reported in previous studies with preservice elementary teachers who experienced a similar instructional approach based on direct moon observations in nature (Trundle et al., 2002, 2006, 2007b). In fact, the rates of conceptual change demonstrated by the participants in this investigation are among the highest of any reported in previous research on moon phase conceptions (e.g., Callison & Wright, 1993; Sadler, 1987; Stahly et al., 1999; Targan, 1988; Trundle et al., 2002, 2004, 2007a; Zeilik, Schau & Mattern, 1999).

What was it about the technology-enhanced instruction that resulted in this impressive rate of conceptual change about moon phases? As with any instructional intervention involving technology, the answer to this question is complex and involves the interaction of the technology and pedagogical approach. The design of the present, largely descriptive, investigation does not permit the delineation of the relative roles of these individual components of the successful curriculum. Still, there are critical features of the software and instructional approach used in the present investigation that are very likely to have played a role in the positive outcomes, especially when considered and contrasted with the results of previous research. Thus, it appears that the success of the instructional intervention in this investigation was due, in part, to a combination of two factors:

(1) The ease at which *Starry Night Backyard* allowed students to do things they would otherwise find very difficult (i.e., make observations at consistent times and vantage points, measure angular separation accurately, and collect observations for two full lunar cycles without gaps).
(2) The instructional model in which the instructor employed the computer simulation.

What follows is a discussion of these factors set within the context of research on teaching and learning about moon phases and about effective and ineffective uses of technology to support conceptual change and inquiry instruction.

Features of the Simulation

At a general level, several researchers have commented on, and found evidence for, the potential of computer simulations to promote conceptual change (Tao & Gunstone, 1999; Windschitl & Andre, 1998; Zietsman & Hewson, 1986). Well-designed computer simulations can provide ideal environments for conceptual change by encouraging students to compare their own conceptions to the underlying scientific conceptions of the program. Furthermore, computer simulations can facilitate students' formulation and testing of hypotheses, and provide a vehicle for reconciling discrepancies between their personal ideas and what they observe in the simulation (Zacharia, 2003). The participants in the present study used *Starry Night Backyard* to compare their personal understandings about moon phases to what they could observe from the program. When their ideas did not match their observations, the participants discussed the differences and proposed tentative explanations.

Certainly, conceptual change can occur outside a computer simulation environment—indeed, the instructor in the present investigation has employed a conceptual change model of instruction in previous studies utilizing direct observations of the moon in nature with positive results (Trundle et al., 2002, 2004, 2006, 2007a,b). However, the results of the present study suggest that specific features of the computer simulation may provide a superior context for addressing preservice teachers' preconceptions about moon phases. These features are described as follows:

(1) The computer program made it easy for students to observe consistently from the same location and at the same time on consecutive nights. Making consistent observations of the moon has proven difficult for students in previous investigations (Abell et al., 2002). Yet, without consistent observations, students have difficulty recognizing the easterly motion of the moon and the gradual changes in the moon's shape from night to night. A critical component of the instructional intervention required students to connect their concrete observations to more abstract models and explanations. By reducing the extraneous variables inherent in making observations at different times and at different locations, the computer simulation allowed students to focus more directly on the target phenomenon. Thus, the computer simulation served to simplify the complexity of the sun–moon–earth system and lower the cognitive load required to recognize patterns and discern causal relationships.

(2) The computer interface allowed students to make more consistent and accurate measurements of angular separations (i.e., the angular distance between the moon and the sun) than was possible with direct observations. This information was critical in facilitating students' abilities to connect their observations of the moon (whether real or simulated) to the psychomotor activity modeling activity they subsequently completed in class. The version of *Starry Night* used in this investigation provided a maximum field of view of only 90 degrees (a limitation not present in more recent versions of the program), which prevented the participants from easily measuring angular separations of the sun and moon between the gibbous and full moon phases. Even with this limitation, the participants collected enough data (a) from new moon to first quarter to see that the angular separation was increasing as the moon waxed, and (b) from third quarter to new moon to see that the angular separation was decreasing as the moon waned. The participants used this information as a bridge between their observations with the computer simulation and the psychomotor modeling activity they completed at the end of the unit. In this manner, the computer simulation facilitated students' abilities to generate and test explanations of the causes of moon phases.

(3) The participants used the computer simulation to make a greater quantity of observations of the moon. This despite the fact that the computer simulation-based

> instruction required substantially less time than did the direct observation approach used in previous investigations (6 instructional hours during class time over 4 weeks versus 8 instructional hours during class time plus individual observation time over 9 weeks). In previous studies, participants' direct observations of the moon were often thwarted by poor weather and various scheduling difficulties, resulting in as few as 39 actual observations over the 9-week observational period (Trundle et al., 2002, 2007b). In contrast, the computer simulation freed participants in the present study from the constraints of weather, obstructions, and scheduling difficulties, enabling them to complete a total of 63 observations. The more complete data set was likely a major factor in facilitating the high level of conceptual change among the participants.

Model of Instruction

The fact that our participants used the computer simulation to complete a greater number of observations and to synthesize scientifically accurate causal relationships contrasts with the findings of recent investigations using educational technologies. As described above, specific features of the simulation and its ease of use likely played a role in the participants' successful use of the computer simulation to support their learning. An additional factor may have been the instructional model accompanying the technology use, as discussed in the next section. The way that the instructor used the computer simulation to support inquiry about moon phases in the present investigation differs from the ways that instructors used technology in previous investigations in which the technology did not support inquiry instruction.

Marshall and Young (2006) found that as a group of three preservice teachers used a computer simulation on kinematics, their attention shifted from planning and conducting experiments to processing feedback. Setting up and completing collision experiments using the computer simulation took the group twice as long compared to setting up similar physical experiments. Furthermore, even with the additional time, they were able to complete only half as many experimental cycles, which in turn, impeded the refinement of their tentative theories and causal explanations. It is clear, however, that the three participants did not know how (or did not choose) to use all of the relevant features of the physics simulation. Additionally, these science majors were expected to design and interpret their simulated experiments with little to no input from the instructor. As described in the Methods Section of the present study, the instructor taught the participants how to use key features of the computer simulation, and provided support and scaffolding to facilitate learning from the inquiry-based activities. The students were not left to fend for themselves.

Waight and Abd-El-Khalick (2007) found that technology tended to restrict, rather than promote inquiry in a sixth grade classroom. The researchers compared student discourse and thinking during a hands-on inquiry unit to a similar unit in which educational technology was utilized. They found that both the teacher's and students' views of the role and authority of the technology served to undermine its potential to have a positive impact on student inquiry by limiting student discourse and engagement in scientific thinking. Participants in the present study, on the other hand, used their observations from the computer simulation as a springboard for discussion and deeper engagement with the phenomenon of moon phases. This did not happen by accident, but was an explicit goal that was planned for and purposively enacted by the instructor through questioning, careful scaffolding of activities, and providing a safe environment for students to express their thinking and to discuss tentative explanations.

In addition, the instructor in this investigation specifically employed the computer simulation within a conceptual change model of instruction. As described in the Methods Section, the instructor elicited her students' ideas about moon phases prior to instruction, and had them share and reflect on their understandings of moon phases during the data analysis. The extensive nature of the moon phase instruction reflected the instructor's belief that changing her students' alternative conceptions would be an incremental process. Students used the computer simulation to collect a body of data that served as a focal point for class discussion about the utility of their ideas about moon phases, and as a venue for developing tentative explanations and testing predictions that stemmed from these explanations.

Unlike the use of technology in some previous investigations, the computer simulation in the present study did not become the focus of instruction, but played a supportive role. With the dual goals of achieving conceptual change while modeling effective science teaching, the early childhood science methods instruction focused on assessing, challenging, and revising the participants' conceptions. Her students' attention, in turn, was centered on their own conceptions of moon phases, how the data they collected supported or contradicted these conceptions, and what alternatives were available that were better aligned with the evidence they had collected. Thus, the computer served to run in the background as a way to consistently collect reliable data, rather than in the foreground as a dominant feature of the instruction. The positive results of this approach support the view that educational technologies should facilitate established effective instructional methods, rather than replace them (Flick & Bell, 2000).

Future Research

In addition to the substantial positive gains in the preservice teachers' understanding of lunar concepts, the participants also enjoyed using the software and several reported that they intended to purchase the program for use in their teaching. One participant said, "I would love to use this program in the future with my students. I understand moon phases and I also now realize how powerful collecting data can be." Another reported, "I think this is a great software program because it allows every person to see the moon. This is especially great for teaching students who live in a city where it is hard to see the moon." Other students reported that using the software gave them confidence to integrate additional software into their teaching. For example, a student said "I now know how to use the *Starry Night* software and it gives me confidence that I can successfully use it and other software in my science teaching. I plan to look for other software to enhance my teaching." Future research should seek to characterize the intentions and instructional practices of teachers who have completed the instructional intervention described in this report in order to determine the degree to which changes in moon phase conceptions result in changes in their instructional practice. In other words, do participants who have benefited from the use of computer simulations effectively use computer simulations in their own instruction to facilitate conceptual change among their pupils?

The 9 weeks of moon observation data that the participants collected from the *Starry Night Backyard* computer simulation provided the foundation for their eventual conceptual change in this investigation. However, having students collect 9 weeks of data may not be realistic for all classroom settings, even with the increased efficiency of a computer simulation. Other researchers utilizing similar instructional interventions have had students collect four weeks of moon observations from nature (Abell et al., 2002) and as little as three weeks of observations from a computer simulation (Bell, Binns, & Smetana, 2007). Thus, a practical direction for future research would be to determine the minimal number of moon observations necessary to elicit desired conceptual change for preservice teachers and school-aged children.

The increased availability of computer projectors permits the collection of observation data from simulations like *Starry Night Backyard* to be collected in a whole-class setting. Thus, it would be helpful for future research to explore the relative benefits of using such simulations as teacher-led demonstrations versus having students use the software individually or in pairs (as was the case in the present investigation). Such an approach, if shown to be effective, could allow for increased scaffolding on the part of the teacher, while limiting the need for purchasing multiple copies of commercial software and providing multiple computers.

This study demonstrates that well-designed planetarium software combined with appropriate instruction can be effective in improving students' conceptions of moon phases. Thus, our results support the growing body of research indicating that computer simulations can be an important vehicle for supporting conceptual change (e.g., Brna, 1987; Gorsky & Finegold, 1992; Zacharia & Anderson, 2003; Zietsman & Hewson, 1986). Further, our results suggest that at least in some ways, a computer simulation may be more effective than direct observations of the moon in facilitating conceptual change. However, before drawing such a conclusion, additional research is needed that directly compares the effectiveness of the computer simulation-based approach to other more traditional approaches to instruction about moon phases. The authors of the present study are currently conducting a quasi-experimental investigation from a common pool of participants to accomplish this objective.

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