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Using a Planetarium Software Program to Promote Conceptual Change with Young Children

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Abstract This study explored young children's understandings of targeted lunar concepts, including when the moon can be observed, observable lunar phase shapes, predictable lunar patterns, and the cause of lunar phases. Twenty-one children (ages 7–9 years) from a multi-aged, self-contained classroom participated in this study. The instructional intervention included lunar data gathering, recording, and sharing, which integrated *Starry Night* planetarium software and an inquiry-based instruction on moon phases. Data were gathered using semi-structured interviews, student drawings, and a card sorting activity before and after instruction. Students' lunar calendars and written responses, participant observer field notes, and videotaped class sessions also provided data throughout the study. Data were analyzed using constant comparative analysis. Nonparametric statistical analyses were also performed to support the qualitative findings. Results reflected a positive change in children's conceptual understanding of all targeted concepts including the cause of moon phases, which is remarkable considering the complexity and abstractness of this spatial task. Results provided evidence that computer simulations may reduce the burden on children's cognitive capacity and facilitate their learning of complex scientific concepts that would not be possible to learn on their own.

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Introduction

Much of the cognitive and science education research indicates that students come to formal science instruction with personal knowledge systems which result from everyday experiences (Duit and Treagust 1998; Vosniadou and Brewer 1994; Vosniadou and Ioannides 1998). Often, these systems, including understanding lunar concepts, are in stark contrast with scientifically accepted views. Alternative views can be resilient to change and present a major barrier to developing scientific understandings through conventional teaching strategies (Wandersee et al. 1994). Much of the alternative conception research has shown that school-aged children (e.g., Barnett and Morran 2002; Stahly et al. 1999), university students (e.g., Zeilik et al. 1999), and teachers (e.g., Trundle et al. 2002) have difficulty learning lunar concepts. Educational research reflects the growing interest in students' science conceptual frameworks and how alternative conceptions can be used to design more effective instructional interventions (Baxter 1989; Vosniadou 1991; Vosniadou and Ioannides 1998).

Conceptual change related to science knowledge and understandings is considered to be an evolutionary process in which there may be a complex interaction between existing conceptual understanding and the learning context (Barnett and Morran 2002). Various models of conceptual change suggest ways to support and promote scientific understanding in the classroom. Vosniadou et al. contend that naïve understandings, entrenched beliefs, may constrain a student's development of a scientific view. Change may occur over time with multiple experiences and may

involve not only cognitive aspects of learning, but may reflect other influences, like the individual's beliefs, motivational needs, learning attitudes, and situational and cultural contexts (Vosniadou et al. 2001). Change may be facilitated when students interact with a curriculum that provides an experiential base in which students are afforded the opportunity to test and investigate their existing understanding through scientific discourse and meaningful events (Muthukrishna et al. 1993). Students often need experiences that allow them to formulate questions, test those questions, and communicate findings and questions within a community of learners (Yager 2005).

Many studies identify common alternative conceptions held by individuals about lunar understandings (Baxter 1989; Bisard et al. 1994). However, relatively few studies focus on the conceptual changes in young students' understanding after an instructional intervention (Barnett and Morran 2002; Stahly et al. 1999). As Parker and Heywood (1998) stated, the research paradigm needs to move beyond identifying the concepts students hold and move toward key features of the learning process and how these features can be more effectively supported. More research is needed to determine if the lunar phase content in the *National Science Education Standards* (National Research Council (NRC) 1996), including observing, describing observations, and finding lunar patterns, as expected of K-4 students, is appropriate for young children. Also, more research is required to determine effective instructional interventions that will support young students' understanding of lunar concepts.

In addition to the need for more research in this area of conceptual change, other factors contributing to the conceptualization of this investigation included trends in science education related to using inquiry and technology as pedagogical tools, as well as educational research related to conceptual change theory in the science classroom.

Inquiry-Based Instruction

The *National Science Education Standards* (NRC 1996) suggest that in order for deep conceptual understanding to occur students should use inquiry to guide explorations. According to the standards, students:

> …acquire knowledge and develop a rich understanding of concepts, principles, models, and theories. … [Students] will learn science in a way that reflects how science actually works (p. 214).

In addition, the standards also support guided scientific inquiry and collaborative work to conduct science investigations (NRC 1996). Scientific inquiry refers to the ways in which scientists investigate our natural world, and inquiry is recognized as being a way that may encourage students to think scientifically about everyday events (American Association for the Advancement of Science [AAAS] 1993). Inquiry, including using investigative skills, like observing, inferring, posing questions, forming hypotheses, and finding some conclusion based on the analysis of data, is similar to the work of a scientist. Inquiry learning implies an active process of constructing meaning in the science classroom. According to Anderson (2007), inquiry learning, like constructivist learning, is an active process with individuals constructing personal meaning. Meaning for the individual is context dependent and enriched through various opportunities with others.

One study reported significant positive changes in young students' scientific understandings of lunar concepts after introducing an instructional intervention that combined both scientific inquiry (investigative skills) and inquiry learning. Trundle et al. (2007) had positive results when using an inquiry-based instruction with elementary children. In this study, 48 Grade 4 students worked collaboratively to gather, record, and analyze moon phase data. The guided inquiry activities used with the elementary school participants were taken from *Physics by Inquiry* (McDermott 1996). The instructional tool appeared to provide the type of structure needed to support or scaffolded learning. According to the *National Science Education Standards* (NRC 1996) and the *Benchmarks for Science Literacy* (AAAS 1993), understanding the cause of moon phases is too conceptually demanding and considered to be an inappropriate expectation for Fourth-grade students. However, most students in this study were able to scientifically explain the cause of moon phases after instruction.

In a more recent study Trundle and colleagues (Trundle et al. in press) found that guided inquiry-based instruction was effective in promoting middle school students' conceptual understanding of lunar phases.

Research results in other science content areas indicate that inquiry-based instruction can be effective in supporting student learning. Chang and Mao (2001) compared the effectiveness of two instructional approaches with junior high school students in Taiwan. Earth science was taught to a treatment group ($n = 319$ in eight randomly selected classrooms) employing the inquiry-group instruction. The control group ($n = 293$ in eight randomly selected classrooms) was taught using traditional methods, including teacher lectures and textbook lessons. After the 4-week intervention, data were collected using Earth Science Achievement Test and an attitude measure. Findings revealed that the inquiry-group scored significantly higher on the achievement test than the traditional approach group. The researchers stated that the inquiry-group method of instruction was superior in supporting student

achievement and attitude toward earth science possibly because the approach encouraged students to plan, discuss, interpret, and problem solve. On the attitude measure the inquiry-group demonstrated more classroom involvement and greater confidence level than the control group. The researchers stated that the inquiry methods emphasized both of these domains because it placed the student as the *knowledge pursuer*.

Inquiry-based instruction also can foster the inquiry skills of elementary students. Cuevas et al. (2005) examined the impact of science inquiry-based instruction on the ability to conduct science inquiry in third- and fourth-grade classrooms with children ($n = 25$) representing diverse linguistic and cultural groups. In the study children were taught inquiry processes using an inquiry framework that provided guided support initially. Explicit instruction and teacher-scaffolding was gradually replaced with student-centered inquiry. The results after teaching two science units using the instructional intervention demonstrated positive effects regardless of gender, achievement, SES, ethnicity, home language or English proficiency.

Technology-Enhanced Instruction

Another trend in science education is the effective integration of technology into classrooms (International Society for Technology in Education [ISTE] 2003). The *National Science Education Standards* (National Research Council 1996) suggest that all students in grades K-4 should develop the ability to use and understand science through technology and technological tools that help students make better observations and measurements (p. 138). Using technology to support scientific inquiry can be an effective way to gather, analyze, and interpret data (Songer 2007). Technology and the use of visual representation is a way to engage students in active inquiry, and if designed effectively, these methods can support learning in the science classroom (Akpan and Andre 2000; Bayraktar 2002; Trundle and Bell 2003; Yair et al. 2001). Computer simulations, compact discs, videos, and the Internet are examples of pedagogical tools that supplement and complement science learning about concepts and events that can often be abstract or difficult to observe (Alvermann 2005).

Indeed, Trey and Khan (2008) found that dynamic computer-based analogies may enhance college students' learning of unobservable phenomena in chemistry. Likewise, an adaptive web-based program was effective in promoting students' conceptual understanding of combustion. Students in the experimental group performed significantly higher on combustion achievement test than students in the traditional instruction group in both post and delayed post-test (She and Lee 2008). Computer assisted instruction also was reported to be effective in enhancing high school students' understanding of chemical bonding. Students in the experimental group obtained significantly higher scores on a chemical bonding achievement test than students in the control group. Also, students in the experimental group exhibited fewer chemical bonding-related misconceptions than the students in the control group after instruction (Ozmen 2008).

In a mixed methods study Ucar et al. (2007) found a significant increase in preservice teachers' test scores after completion of technology-enhanced instruction on the cause of tides. Using archived web-based data, participants gathered and analyzed several months of tidal data from various geographic locations within a short amount of time. Large quantities of data that was easily accessible to the participants, when integrated into inquiry-based lessons, appeared to support the participants' conceptual change to a scientific understanding of tides.

Trundle and Bell (2009) explored preservice elementary teachers' ($n = 157$) understanding of moon phases and the cause of lunar phases before and after an inquiry-based instructional intervention. Three instructional treatments were compared: One group collected lunar data using only planetarium software, *Starry Night*; the second group used both *Starry Night* and natural observations; while the third treatment group collected data from natural observations only. Before instruction none of the participants held complete scientific understandings related to all the targeted lunar concepts. After the instruction all three treatment groups demonstrated substantial gains in all the targeted concepts. Even though there were no significant differences among the three treatments in regard to participants' abilities to draw scientific moon shapes or in their conceptions of the causes of moon phases, the *Starry Night Only* group showed statistically greater gains for sequencing the moon phases. Thus, the three treatments were equally effective in facilitating desired conceptual change.

In an experimental study, 66 fourth and fifth grade students from a Finnish school were placed into three different environments to learn simple concepts of electricity (Jaakkola and Nurmi 2008). The environments included: a computer simulation, a laboratory setting, and a simulation-laboratory combination. The results revealed learning gains overall for each group. However, the greatest gains in learning were experienced within the group assigned to the combination of the computer simulation and the hands-on laboratory experience. The researchers concluded that the computer simulation offered initial theoretical principles of electricity, and the hands-on laboratory offered opportunities to test the principles.

Targeted Science Concept

The *National Science Education Standards* (National Research Council 1996) target the understanding of lunar concepts as part of scientific literacy, including Grades K-4. Students at this level are expected to study the patterns of movement and observable phase changes in the moon. The standards for Grades 5–8, which are more conceptually demanding, expect students to find evidence of changes in moon phases, as well as determine the cause of moon phases. The *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS] 1993) states that teaching about the cause of moon phases should occur in grades 6–8. The scientifically accurate explanation for the cause of lunar phases states that "despite half of the moon being illuminated by the sun at all times, the portion of that half that can be seen from Earth—what we call the phase- depends upon the relative positions of the sun, Earth, and moon" (Bailey and Slater 2003, p. 5).

Although young children are not expected to understand more sophisticated concepts that follow in the middle grades like cause of the lunar phases, recognizing the patterns of observable moon shape changes is considered as an appropriate task for children in grades K-4. The *Atlas of Scientific Literacy* (American Association for the Advancement of Science [AAAS] 2001) suggests that basic concepts (e.g., recognizing that the appearance of the moon changes every day and the moon can be observed sometimes at night and sometimes during the day) lay the foundation for understanding more advanced concepts in later grades (e.g., the cause of the moon phases). As researchers and science educators, we agree with the hierarchical relationship among the concepts suggested in the *Atlas of Scientific Literacy.* However, findings from our previous study (Trundle et al. 2007) and studies by other researchers (Barnett and Morran 2002) have challenged the assumption that the understanding of cause of the lunar phases is too difficult a task for young children to accomplish. Thus, we hypothesized that the concurrent teaching of these hierarchical concepts might be effective with young children if guided inquiry based activities with computer simulations are implemented. The point made in our study is not that the cause of the lunar phases is an important concept that young children must learn. Rather, children can learn more advanced concepts in addition to developmentally appropriate concepts with the help of guided inquiry activities supported with computer simulations.

Understanding the cause of moon phases can be challenging and involves thinking in three dimensions and from two different perspectives (Suzuki 2002). One perspective includes viewing the moon from the Earth perspective, while the other perspective requires the inference of what would be seen when looking down on the sun, Earth, and moon from outside the system. This effort places a considerable amount of burden on young learners' cognitive processing capacities. Computer simulations can reduce the burden on cognitive capacity by providing two perspectives dynamically in a virtual environment. By reducing the cognitive load (Sweller 1988), simulations might make it possible for young children to learn the science concepts that some educators believe to be developmentally inappropriate. Therefore, the current study investigated the efficacy of using a computer simulation to promote young children's conceptual understanding of the cause of the moon phases.

Purpose

The purpose of the current mixed methods study was to address and describe young children's conceptual understandings about patterns in and the cause of lunar phases before and after an inquiry-based instructional intervention which integrated technology. The following research questions guided the investigation:

What do Primary children know about when the moon can be observed before and after inquiry-based instruction?

What do children know about observable moon phase shapes and sequences before, during, and after inquiry-based instruction?

What do children understand about the cause of moon phases before and after inquiry-based instruction?

Methods

Context

The research was conducted in a Midwestern suburban school district with the population of approximately 15,000 students. The school where the study took place had an enrollment of 505 students in grades Early Primary (kindergarten, first-grade students) through Intermediate (fourth-, fifth-grade students). The context was the natural setting within one Primary (second-, third-grade) classroom. The classroom contained five computers with planetarium software, and two large community calendars that were prominently displayed.

Participants

Twenty-one children (12 boys, 9 girls) from a self-contained multiage classroom participated in the research

study. The children ranged in age from 7 to 9 years. Most of the student population within the school setting was Caucasian (84.55%). A small percentage of the students received free or reduced lunch (8.31%), indicating a low level of poverty in the school. Within the heterogeneous classroom where the study took place, seven of the students were identified as cognitively gifted, while three students received special support services.

Most children in this study were adept with using computers. The elementary school in which this study was conducted was considered well-equipped with technology, with each classroom containing 5 or 6 computers. Students also had access to a full computer laboratory and a mobile 16 unit laptop cart. All computers had Internet connectivity. Children in this school begin using computers in Early Primary (kindergarten) classrooms.

The participants created five self-selected working groups, consisting of four or five students per group. During the science exploration periods, the students self-regulated their recording and sharing of lunar data. During the analysis period the instructional intervention was initially introduced by the participant observer, but actively regulated by the participants. This age level of participants was selected based on the *National Science Education Standards* (National Research Council 1996) which state that understanding lunar phenomena is part of the curriculum included in the K-4 Earth and Space standard.

Instructional Materials

Starry Night, the planetarium software from Imaginova, allowed children to explore moon phases and gather observational lunar data. Using the planetarium software, children were able to manipulate environments, set times to watch moonrise and moonset, and track the moon's dynamics easily and efficiently from the classroom. Collecting and checking lunar data could be done in relatively little time. *Physics by Inquiry* (McDermott 1996), an inquiry-based instruction, allowed for guided inquiry investigations through specifically designed activities. The students: (1) gathered, recorded, and shared moon data based on their observations, (2) analyzed their moon data, and (3) modeled the cause of moon phases. It is important to note that the McDermott materials were designed to teach teachers science content through guided inquiry-based activities. The current study transfers the instructional intervention into a primary classroom.

Instruction

The instructional intervention utilized in this study was designed based on the findings of previous research, which indicate that the use of a well-designed simulation to gather observational data is at least as effective as observations in nature alone or observations in nature combined with a simulation. And in some ways, the simulation is more effective than observations in nature (Trundle and Bell 2009). Thus, the current study used observations gathered with a computer only. Also, observations using a simulation are more time efficient and less frustrating than observations in nature, making observations with simulations more practical for classroom teachers (Bell and Trundle 2008).

The instructional intervention included lunar data gathering and analysis activities (McDermott 1996), which integrated *Starry Night* planetarium software and the inquiry-based instruction on moon phases (Bell and Trundle 2008). Over a 5-week period students collected 9 weeks, or two full lunar cycles, of moon data using the software. The lunar data included the moon disk illumination, the direction of the moon's location in the sky, and the time of observation. Figure 1 shows an example of the sky in the daytime, using *Starry* Night, while Fig. 2 represents the nighttime sky. The observational lunar data were recorded on the student's individual lunar calendar and on the two large community calendars posted in the classroom. At the end of each week the class shared their findings and discussed patterns and anomalies in the data. The extensive collection of data was recommended by the *Physics by Inquiry* (McDermott 1996) curriculum and was consistent with previous research on interventions that promote scientific understanding (Trundle et al. 2002, 2007).

Lunar data analysis began after the data gathering period and included five activities designed for guided inquiry investigations. These activities included: identifying moon shapes and patterns, determining the length of a lunar cycle, sequencing observed shapes, and applying scientific labels and concepts to the moon shapes, and the psychomotor-modeling exercise.

In small working groups children looked closely at their calendars containing 63 days of moon data. Initially children were encouraged to look for repeating patterns in the way the moon's shape changed over time. If participants recognized patterns, they were asked to describe the changes in the moon's appearance. Participants were asked if the change from one shape (phase) to another happened gradually or quickly.

Next, participants were asked to determine the length of a lunar cycle. In order to determine the length of one cycle, the children numbered the 63 days of their moon observations sequentially, beginning with the first observation as number "1". Children were asked to find a distinctive shape on their moon calendar, noting its "day" number. As carefully as possible, the students recorded the "day" number when the same shape reappeared on their calendar. Children were asked to find the difference between the

Fig. 1 *Starry Night* example of moon observation in a daytime sky

Fig. 2 *Starry Night* view of moon in nighttime sky

"day" numbers either by counting the days between the identical phases or by subtracting the "day" numbers. The process continued with other distinctive shapes, until participants were satisfied that the approximate time of a lunar cycle is 30 days.

On another day small working groups of participants were given a copy of eight representative moon shapes. The children, while using their moon calendars, were asked to arrange the phases in the sequence that they observed them occurring during the data collection period. After sharing and discussing the sequence, the shapes were cut apart and glued or taped in their moon journals.

Applying scientific labels to the moon shapes occurred next. Up to this point children used their own language to describe the moon phases. Many knew the *full moon* and *new moon labels*. The children observed and discussed how they saw more of the moon's illumination during the *waxing moon series*, and the children found examples of the waxing sequence in their moon calendar. Also, the children identified examples of times when they saw less of the moon's illumination each day, and that series was labeled as the *waning series*. All eight representative moon phases were named and labeled. A larger version of poster-sized moon phases, painted by the children, also were labeled and hung in the room.

The final activity included the psychomotor-modeling exercise in which the children modeled the sun-earth-moon relationships with models of the sun (an exposed light bulb), moon (Styrofoam ball), and earth (child's head for a personal, earth viewer perspective). In this activity, students observed the changes in lunar phases, while the "moon" orbited the "earth" and completed an entire lunar cycle.

This activity was designed to promote a scientific understanding of the cause of the moon phase as the children modeled the phenomenon using a three-dimensional environment. One child from each working group began the task. Children took turns modeling, while the other children coached or observed.

First, the teacher demonstrated how to use the models. Then, each child had an opportunity to extend the Styrofoam ball (moon) at arm's length, slightly above their head (earth perspective) and toward the bulb (sun). As each child revolved with the Styrofoam ball extended, he/she was asked to notice the lighted portion of the ball. Oral prompts included:

Using the Styrofoam ball and the bulb, move the moon (Styrofoam ball) and notice the lighted portion. How does the lit portion change as you move the moon? Are there any changes that remind you of the moon's phases that we observed? Can you move the moon to reproduce the phases in the order that we observed? If so, which way should we move, clockwise or counterclockwise?

Other prompts included: Stop the moon (ball) in front of you (Earth). What part of the moon is illuminated? Turn to face away from the sun (bulb). You on Earth have made a half turn. Are you noticing any changes in the moon's appearance? Continue moving. Go back to the starting position with the moon (ball) extended in front of you toward the sun (bulb). What do you notice?

The children were encouraged to complete the moon's revolution around Earth several times, noting the lighted portion they could see on the Styrofoam ball (moon). Children were asked: "*Can you reproduce all of the eight representative moon phases in the correct order using the ball and light bulb? How is this like the moon phases that we observed and recorded?*" After the psychomotor activity and the classroom discussion, the students were asked to write in their moon journal. This writing reflected the child's thoughts, questions, and observations made during the task.

Researcher

The participant observer (first author) videotaped all class sessions, took field notes, informally questioned students for clarification, introduced software features and how to collect lunar data, led weekly lunar data sharing sessions, and led the inquiry-based instructional activities. The participant observer also transcribed, coded, and analyzed the student data, which were collected prior to and after the instructional intervention. The participant observer was an experience classroom teacher with 25 years of teaching experience. However, the teacher was a novice with this particular instructional intervention in that she had never taught the lessons prior to the study.

Data Collection and Analysis

Multiple data sources were used to describe the participants' conceptions of lunar phase shapes, waxing and waning sequences of phases, and the cause of phases. Data were collected at various points during the study using semi-structured interviews, student drawings, card sorting, lunar calendars, written responses, participant observer field notes, and videotaped class sessions. The data were transcribed and coded to identify knowledge and understandings each participant held before and after the intervention. The students' written responses were used to describe student knowledge of when the moon could be observed. Drawings of moon phases indicated what children knew related to observable shapes, while card sorting and sequence drawings of moon phases highlighted what children knew about the sequence of moon shapes. The data from the interview helped identify and describe the children's conceptual understanding of the cause of moon phases. Data were analyzed using constant comparative analysis. Using a "partial" coding framework based on previous research (Trundle et al. 2002), categories of conceptual understandings were established, including scientific understanding, scientific understanding with alternative fragment, scientific fragment, alternative understanding, alternative fragments, and no conceptual understanding of the topic.

To make statistical analysis possible children's pre- and post-conceptual understandings of the cause of moon phases were scored with a rubric (Sackes and Trundle 2009). Children were given scores ranging from 0 to 10 based on the number of scientific elements and alternative mental models included in their conceptual understanding. Children's moon drawings were also scored, 0 point was given for nonscientific moon shapes and sequences and 1 point was given scientific shapes and sequences. Quantitative data were analyzed using nonparametric tests, including the Wilcoxon Signed Ranks test and the McNemar test.

Findings

Qualitative Findings

Time of observation. The first research question focused on when the moon can be observed. Before instruction most children (76.2%) responded on a questionnaire that the moon can be observed only in the nighttime sky, which is a common alternative conception. Only one student (5%) reported that the moon can also be seen at times in the daytime sky. There was a notable change after the instructional period. Nearly all of the participants (95.2%) responded on a questionnaire that the moon can sometimes be seen in the nighttime sky, while most (81%) responded that the moon can also be seen sometimes in the daytime sky.

Shapes and Sequences. A drawing task was used to answer the research question related to student knowledge of observable moon phase shapes before, during, and after

an inquiry-based instruction. Without the instruction, all children included at least one alternative, non-scientific phase among their moon drawings. None of the children drew scientifically accurate representations of all of the eight representative moon shapes (i.e., the new moon, waxing crescent, first quarter, waxing gibbous, full moon, waning gibbous, third quarter, and the waning crescent). During the instructional period and before the psychomotor modeling activity, students drew more scientific moon shapes, but none drew all eight representative moon phases accurately. After the instructional period more children drew scientific moon phases, while eight students (38.1%) drew scientifically accurate representations of all eight phases. Table 1 summarizes the number of participants who included the moon shapes in their pre-assessment, mid-assessment, and post assessment drawings.

The data related to the knowledge children held about the sequence of the moon phases were gathered through children's drawings and a card sorting activity. The card sorting task was completed during the pre- and post-interviews. Before the instruction most students (76.2%) reported that the moon's phases appear in a predictable sequence, while after instruction all of the children (100%) reported that the moon's phases appear in a predictable pattern. The students who reported that they expected to observe a predictable pattern in the moon phases sequence were asked to draw the sequence they expected to see. Before instruction most children's knowledge of the regularly recurring pattern of moon phases was nonscientific. More children drew the waning and waxing series accurately on the mid-assessment. However, after instruction more children were likely to demonstrate scientific knowledge of the regularly recurring pattern of moon phases. With all of the children participating in the task more than half of the students (12 or 57.1%) drew a scientific waning moon series, while ten students (47.6%) drew the waxing series accurately. Eight of the children (38.1%) were able to draw both the scientific waning and waxing moon phases. The number of students who included scientific and non-scientific moon sequences in their drawings during the pre-, mid-, and post-assessment is included in Table 2.

Table 1 Frequencies of participants drawing specific moon phases (task 1)

Moon phase	Pre-assessment		Mid-assessment		Post-assessment	
	Sci	Non-sci	Sci	Non-sci	Sci	Non-sci
Full	21	0	21	0	21	0
Waning gibbous	0	11	5	7	13	5
Third quarter	9	1	14	1	18	1
Waning crescent	5	11	4	13	14	5
New moon	8	0	15	0	20	0
Waxing crescent	2	7	4	11	13	8
First quarter	8	1	12	0	15	4
Waxing gibbous	1	4	5	4	11	8

The card sorting task was given during the pre- and post-interviews. Children were provided with eight randomly shuffled cards, each containing one representative moon shape. Children were asked to order the cards into the lunar phase sequences they expected to observe. Without instruction only four students (19%) placed the cards in scientific waning and waxing sequences. After the instruction more than half of the students (12 or 57.1%) arranged the card in scientifically accurate patterns.

Cause of Lunar Phases. In-depth interviews provided the data to answer the third research question. The pre- and post-interviews required the participant to explain what he/she thought caused the moon's phases and use three-dimensional (analogical) models of the sun, the Earth, and the moon to accompany their causal explanations. The results for the cause of moon phases are reported in Table 3.

Before instruction eleven children (52.4%) held alternative conceptual understandings about the cause of moon phases. Most of these students reported that the shadow of the earth or some other object was blocking the sun's light to the moon. This finding is consistent with previous research (Baxter 1989; Bisard et al. 1994; Dai and Capie 1990; Schoon 1995; Trundle et al. 2002). Five students (23.8%) held alternative conceptual understandings with one science fragment, while four children (19%) held alternative fragments, and one child (4.8%) held no conceptual understanding. None of the children articulated scientific explanations for the cause of moon phases before instruction.

Following the instructional intervention there was a notable shift with eleven children's understandings (52.4%). These children held a complete scientific understanding of the cause of lunar phases. Two students (10%) held a scientific understanding with an alternative fragment, and one student (5%) held a scientific fragment for the cause of lunar phases. Only seven students (33.3%) continued to hold an alternative understanding after instruction.

Pre-instruction Summary. Students responded in writing regarding when the moon can be observed. Before instruction, only one child understood that the moon can sometimes be observed during the day (4.8%). Without the instruction, all children included at least one alternative, nonscientific phase among their moon drawings, and none of children's knowledge of the both the waxing and waning pattern of moon phases was scientific. Thus, none of the children drew both scientific shapes and sequences. Also, none of the children were able to articulate accurate

Table 2 Frequencies of participants including moon phase sequences

Sequence	Pre-assessment		Mid-assessment		Post-assessment	
	Sci	Non-sci	Sci	Non-sci	Sci	Non-sci
Predictable sequence	16 (Yes)	5 (No)	18 (Yes)	3 (No)	21 (Yes)	0 (No)
Moon waning series	5	8	4	9	12	8
Moon waxing series	4	12	3	11	10	11
Moon waxing and waning series	0	14	0	13	8	12

Table 3 Types of conceptual understanding for the cause of moon phases

Categories of understanding	Pre-instruction	Post-instruction
Scientific understanding	0	11
Scientific understanding with alternative fragments	0	2
Scientific fragment	0	1
Alternative with scientific fragment	5	1
Alternative	11	5
Alternative fragment	4	1
No conceptual understanding	1	0

explanations for the cause of moon phases. In summary, none of the children had a scientific understanding for the targeted concepts in this study.

Post-instruction Summary. After instruction, more children understood that moon can be observed sometimes during the day (17 children, or 81%) and more drew scientific moon phases compared to pre-instruction results (9 students, or 42.9%). More children drew scientific representations of both the waxing and waning moon phase sequences (8 students, or 38.1%). However, most children could draw a scientific waning sequence (12 students, or 57.1%) and many drew an accurate waxing sequence (10 students, or 47.6%). Also, more children drew both scientific shapes and sequences (5 students, or 23.8%), and many understood the cause of moon phases (11 students, or 52.4%). This finding on young children's understanding of the cause of moon phases is remarkable considering the complexity and abstractness of this spatial concept.

Qualitative Results Summary

In comparing children's responses from the pre-assessment to the post-assessment tasks for all of the targeted moon concepts there was a change in understanding from mostly alternative to more scientific. Table 4 summarizes results related to the changes in children's scientific understanding in four areas: scientific moon phase drawings, the waning and waxing sequence drawings, both the scientific shapes and sequences moon drawings, and the scientific conceptual understanding for the cause of moon phases.

Quantitative Results

To support the qualitative comparisons, the McNemar test for two related samples was used to examine the numbers of children who changed in content knowledge of moon phase shapes from the pre- to the post-test based on their drawings. Results indicated that significantly more children drew scientific moon shapes on the posttest than on the pretest ($p = .016$). Results for the drawings of moon phase sequences were similar in that significantly more children drew scientific moon sequences on the posttest than on the pretest ($p = .008$). Also, significantly more children drew both scientific moon shapes and sequences on the posttest compared to the pretest ($p = .031$).

A nonparametric statistical test was used to examine the shifts in conceptual understanding from alternative to scientific from pre- to the post-interview. Children's conceptual understandings were scored with a scoring rubric designed in a previous study (Sackes and Trundle 2009). Children's pre- and post-interview scores were compared using the Wilcoxon Signed Ranks test. Results indicated that significantly more children expressed, through modeling and interview comments, scientific understandings of the cause of the moon phases on the post-test compared to the pretest ($Z = 3.64$, $p < .001$). The effect size for the result was calculated as described in Clark-Carter (2004). The effect size was $r = .79$, indicating instructional

Table 4 Participants' responses coded as scientific

Targeted moon phase concepts	Pre-assessment (%)	Post-assessment (%)	Gain (%)
Scientific moon phase drawings	0 (0%)	8 (38.1%)	38.10%
Scientific waning and waxing sequence drawings	0 (0%)	8 (38.1%)	38.10%
Both scientific phases and sequence drawings	0 (0%)	5 (23.8%)	23.80%
Scientific cause of moon phases interview responses	0 (0%)	11 (52.4%)	52.40%

intervention had a high impact on children's conceptual understanding of the cause of the moon phases.

Discussion

Many previous research studies of young children's understandings of lunar concepts were descriptive, highlighting common alternative conceptions. Relatively few have focused on effective instructional interventions to promote scientific understandings of lunar concepts. Students in Grades K-4 are expected to study patterns of the moon's movement and observable changes in moon phases, while Grade 5–8 students are expected to find evidence of change and determine the cause of moon phases (National Research Council 1996).

The aim of the present study was, therefore, to examine young students' ideas about observable moon phases, moon phase sequences, and patterns of sequences prior to and following an inquiry-based instruction which utilized a computer simulation. In addition to the recommended standards for the Grade K-4, students explored the cause of lunar phases which is considered developmentally inappropriate due to the heavy cognitive demand involved with this concept.

Before instruction most participants reported observing the moon only at night. Collectively the participants demonstrated little scientific understanding of the observable moon shapes and sequences. In addition, none of the participants articulated a scientific explanation of the cause of moon phases. However, after the inquiry-based, technology-enhanced instructional intervention, most participants showed positive changes in their understandings of not only the concepts recommended in standards but also the cause of the moon phases.

The concept of the cause of the lunar phases is considered developmentally inappropriate because learning of this concept places a considerable amount of burden on young children's cognitive processing capacities. We hypothesized that computer simulations can reduce the burden on cognitive capacity by providing two perspectives dynamically in a virtual environment, thereby, making it possible for young children to learn the cause of the lunar phases. In other words, computers, as mental tools, can act as a resource and provide a structure of support that allows children to learn complex scientific concepts that would not be possible to learn on their own (Hewson 2004; Saljo et al. 2006).

Complex science concepts, such as the cause of the moon phases, require learners to pay attention to and process a large number of knowledge elements and the relationship among them. Due to excessive taxing on cognitive resources in learning complex scientific concepts, young learners are left with little or no cognitive processing capacities to construct a scientific mental model of the cause of the lunar phases (Sweller 1988; Sweller and Chandler 1994).

In the present study, the computer simulation, by acting as an extension of learners' cognition, freed some of the cognitive processing capacities and reduced the amount of cognitive load on young learners' cognition (Pea 1993; Sweller 1988). By making available the cognitive processing capacity necessary to construct a scientific mental model, the computer simulation facilitated children's construction of the scientific understanding of the cause of the moon phases.

For the children in this study, the nature of the instruction and its facilitation appeared to make changes in young children's understandings. A growing body of research supports the integration of technology into the science classroom (Bell and Trundle 2008, 2009; Jaakkola and Nurmi 2008; Songer 2007). Children in this study addressed observed simulated phenomena through the support of *Starry Night* planetarium software. The use of computer simulation facilitated children's conceptual change by providing a structure of cognitive support, acting as an extension of their cognition, and reducing the amount of burden on their cognitive processing capacities. Thus, the computer simulation made it possible for children to learn a complex scientific phenomenon that they were not likely to learn independently. Children gathered and collaboratively analyzed their own data through discussion and scaffolded inquiry-based tasks (McDermott 1996). The collaborative learning in this study was viable for these young children. This particular approach to learning also gave students a strong sense of ownership in their work.

There are several implications of the results of the present study for curriculum developers and classroom teachers. The findings of this study challenge the previous assumptions regarding the appropriateness of the concept of the cause of the moon phases for young children. The hierarchical relationship among the concepts suggested in the science curriculum and national standards and its reflection of gradual presentation of science concepts from basic to more advanced ones in following grade levels as a pedagogical practice might be unwarranted. The results of our study suggest that children can learn an advanced, abstract science concept, such as cause of the moon phases, well before the middle grades. The concurrent teaching of basic and sophisticated science concepts might be an effective pedagogical approach if teaching of these concepts is implemented using guided inquiry based activities supported with computer simulations. Future studies should be conducted to determine whether this approach can also be effective in teaching other science concepts or the concepts targeted in the present study with children in different characteristics.

By focusing on young children and exploring their conceptual understandings of lunar phenomenon before and after instruction, the present study makes a contribution to the scientific literature on young children's understanding of lunar concepts, the importance of guided inquiry in the science classroom, and children's effective use of planetarium software to gather data.

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