# Early Elementary Students' Development of Astronomy Concepts in the Planetarium

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Abstract: The National Science Education Standards [National Research Council (1996) National science education standards. Washington, DC: National Academy Press] recommend that students understand the apparent patterns of motion of the sun, moon and stars by the end of early elementary school. However, little information exists on students' ability to learn these concepts. This study examines the change in students' understanding of apparent celestial motion after attending a planetarium program using kinesthetic learning techniques. Pre- and post-interviews were conducted with participants from seven classes of first and second grade students ($N = 63$). Students showed significant improvement in knowledge of all areas of apparent celestial motion covered by the planetarium program. This suggests that students in early elementary school are capable of learning the accurate description of apparent celestial motion. The results also demonstrate the value of both kinesthetic learning techniques and the rich visual environment of the planetarium for improved understanding of celestial motion. © 2008 Wiley Periodicals, Inc. J Res Sci Teach 46: 192–209, 2009

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This study investigates instruction designed to help improve children's understanding of apparent celestial motion: the observable patterns of motion of the sun, moon and stars that occur on a daily, monthly and yearly pattern. Observing and learning the patterns of motion of apparent celestial objects pose a number of challenges. First, all of these motions occur over long periods of time: hours in the case of the daily motion of the sun, moon and stars; daily for the shift in the moon's appearance and rise/set time; monthly for the slow change in the sun's path across the seasons and the change in the constellations we see each night. Second, tracking these motions requires effort to notice and recall positions with respect to landmarks on the horizon. Third, these changes are often occurring when many people are not outside observing the sky such as at night or during inclement weather. Therefore, it is unlikely that most children will learn the details of apparent celestial motion on their own.

Children may benefit from learning about apparent celestial motion in elementary school because it will provide a reason to learn the unobservable motions that *explain* these phenomena. In school, most instruction fails to make the connections between the observed motions in the sky and the *deduced* motions of the planets, sun and moon from a heliocentric (sun-centered) perspective (Nussbaum, 1986). Instruction that primarily focuses on the heliocentric motions is not only unlikely to improve knowledge of geocentric motion, but it may also facilitate students' in creating non-normative ideas about celestial objects and their motion (Plummer, in press). Learning about the apparent motion of the sun and moon may also help students understand other important topics such as the seasons (Trumper, 2006) and phases of the moon (Kavanagh, Agan & Sneider, 2005; Trundle, Atwood, & Christopher, 2002, 2006, 2007a,b; Wilhelm, Smith, Walters, Sherrod, & Mulholland, 2007).

Both the National Science Education Standards (*NSES*; National Research Council, 1996) and the Benchmarks for Science Literacy (*Benchmarks*; AAAS, 1993) include the patterns of celestial motion as part

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of the learning goals for children in early elementary school. Based on these documents, the recommendations for what elementary students should learn can be summarized as follows:

1. Objects in the sky (sun, moon, and stars) all have properties, locations and movements that can be observed and described.
2. Objects in the sky have patterns of movement.
   a. The sun, moon and stars all appear to move slowly across the sky.
   b. The sun appears to move across the sky in the same way every day.
   c. The path of the sun changes slowly over the seasons.
   d. The moon moves across the sky on a daily basis much like the sun.
   e. The observable shape of the moon changes from day to day but looks the same again about every 4 weeks.

The few studies on beliefs about the patterns of apparent celestial motion include Sharp's study of elementary students (1996) and studies of teachers' ideas (Mant & Summers, 1993; Trumper, 2006). Sharp interviewed 42 English students in Year 6 (10–11-year olds) on their beliefs about the apparent "position and movement" of the sun, moon and stars in the sky through verbal responses, sketches and gestures. The majority (76%) were able to give a general description of the sun rising and setting that included moving across the sky from one side to the other. However, most of the children did not believe that the moon appears to move (64%) or that the stars appear to move (86%). While limited in detail, these results indicate that the apparent movement of celestial objects is not well understood by children. Mant and Summers examined the beliefs of 20 primary school teachers in England using a prop that simulated an observer on a small hill, giving the participants a concrete visual to interact with in explaining their answers. A large portion of these teachers held relatively sophisticated understandings of the sun's apparent motion: half of the teachers (50%) knew that the sun passes through the southern sky each day and most (85%) knew that the sun is higher in summer than winter (though only two (10%) gave the fully scientific account, including an accurate description of the sun's rising and setting positions). Trumper's study of 20 Israeli junior high teachers' beliefs about the sun's apparent motion found that only one teacher gave the scientific description of the sun's apparent motion. Similar to the elementary students, fewer teachers in Mant and Summer's study gave scientific descriptions of the moon and stars' apparent motion. While most (80%) were aware that the moon has an apparent motion, only four (20%) knew that the moon rises in the east and sets in the west, and only two of those teachers knew that this follows the sun's path. Only half of the teachers knew that the stars appear to move and only four could give a reasonably accurate (if not complete) description of their east-to-west motion. These results suggest that both teachers and students have a general concept of the apparent motion of the sun, with teachers holding a generally more scientific understanding (though most are still missing key aspects of the sun's apparent motion). However, both children and teachers have limited knowledge of the moon and stars' patterns of motion which suggests that both groups need access to high quality instruction on these topics.

Children and adults also have limited knowledge of another pattern of change in the sky: the cycle of lunar phases. Studies have investigated the knowledge of the observable phases of the moon in American fourth-grade elementary students (Trundle et al., 2007b), English Year 6 students (Sharp, 1996) and American pre-service teachers (Bell & Trundle, 2008; Trundle et al., 2006; Wilhelm et al., 2007; Wilhelm & Walters, 2008). Most children and adults are aware of the crescent phase of the moon but fewer indicated knowledge of the half-moon or gibbous phases. Non-scientific representations of the phases of the moon were also common among both children and adults. Inaccuracies in describing the apparent patterns of the moon's appearance may also be tied to non-scientific explanations for the phenomena. A prevalent view among young children is that the moon's phases are caused by the movement of clouds while many older children and adults use the earth's shadow (the eclipse model) to explain the changing phases (Baxter, 1989; Bell & Trundle, 2008; Trundle et al., 2002).

Because few studies have gone into detail on early elementary students' ideas about apparent celestial motion in ways that focus on their earth-based perspective, an initial study was conducted involving interviews with first, third, and eighth grade students ($N = 20$ at each grade level) to provide a foundation for the present study (Plummer, in press). The results indicate that first grade students have not developed the understanding that celestial objects appear to rise and set, in the same direction, along similar paths. Many do not believe that celestial objects appear to move continuously, instead believing that the sun and moon rise straight up, stay at the top of the sky throughout the day or night, and then set straight down. And while a larger number of the third grade students exhibited more accurate descriptions of the path of the sun and moon than the first grade students, many did not believe that the sun and moon rise and set on opposite sides of the sky. There was also no significant improvement in knowledge of the apparent motion of the stars with half of the third and eighth grade students indicating that the stars either never appear to move or only move at the end of the night. Students at all age levels lacked the scientific understanding of the shift in the sun's path over the seasons. Overall, Plummer (in press) supports the results of previous studies which found limited scientific knowledge of the sun's apparent motion and even more limited understanding of the patterns of motion of the moon and stars (Mant & Summers, 1993; Sharp, 1996; Vosniadou & Brewer, 1994).

There is also limited research on the effectiveness of planetarium education in improving understanding of astronomy. In the 1970s, the planetarium community began to discuss how to actively engage the audience in "participatory planetarium programs" rather than the traditional lecture model (Friedman, Schatz, & Sneider, 1976). Mallon and Bruce (1982) investigated the use of participatory planetarium programs in small educational planetariums, concluding that the participatory oriented program is more effective in teaching constellations, and possibly for improving students' attitude towards astronomy. Bishop (1980) found that model manipulation and drawing in the planetarium can help students learn projective astronomy concepts (such as the day–night cycle and the phases of the moon). Beyond these studies, there has been little published research investigating the use and educational value of participatory planetarium programs. However, a large body of research exists on children learning in science centers (Rennie & Johnston, 2004; Rennie & McClafferty, 1995, 1996).

## Instructional Development and Theoretical Framework

The planetarium was chosen as the educational environment for this study for two reasons. First, as mentioned previously, there is little research on learning in the planetarium despite the fact that there are over a thousand planetariums around the world, serving millions of visitors yearly. Compared to the extent of research on students' prior knowledge and beliefs, there is an overall deficit of research that connects theory to practice in all conceptual areas of astronomy (Bailey & Slater, 2003), though this appears to be improving in recent years (Kavanaugh, 2007). Second, planetarium technology is foremost designed to demonstrate the apparent motion of celestial objects in a simulated sky making this venue a natural fit for the concepts explored in this study. However, most students only visit the planetarium for a short period of time (30–60 minutes) as a one-time event, rather than experiencing continuous instruction in the planetarium environment. Therefore, this study investigates student learning in the same time frame, a single 45-minute planetarium program replicating the average visitor experience.

Ultimately, instruction that improves children's understanding of astronomy should be sustained, in-depth, and make connections to real-world phenomena (Duschl, Schweingruber, & Shouse, 2007). The purpose of this study is not to claim that a single planetarium program is sufficient for radical changes in understanding. Instead, a planetarium visit should be an integrated part of the classroom science curriculum, with connections made between the fieldtrip experience and the classroom for understanding to be retained over a long period of time (Griffin & Symington, 1997; Rennie & McClafferty, 1995). Therefore, this study has the potential to uncover what children can learn from a single planetarium visit and bring back with them to the classroom. Classroom instruction can then be designed to make connections with real-world observations of the sky, investigate additional concepts not understood in the planetarium, and eventually use the children's improved understanding of apparent motion to learn about the rotation and revolution of the earth and orbit of the moon.

### *Instruction That Promotes Conceptual Growth*

Instruction that is successful in altering non-normative ideas considers students' prior knowledge and attitudes toward the subject (Bransford, Brown, & Cocking, 1999; Pintrich, Marx, & Boyle, 1993; Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1992). Regardless of how we design instruction, the learner will interpret experiences and new information according to his or her previously held notions and construct new ideas based on their prior knowledge. Young children have minimal experience with making observations of the sun, moon and stars. Yet they already have developed ideas about the nature of celestial objects and their motion, developed from their naïve physics beliefs (Nussbaum, 1979; Nussbaum & Novak, 1976; Vosniadou & Brewer, 1992, 1994). The instructional intervention in this study was designed to consider the ways in which children at a young age are likely to describe the patterns of celestial motion (Plummer, in press) and provide experiences in the planetarium that will allow them to develop more sophisticated descriptions of these motions.

In the process of moving towards a scientific understanding of the world, learners may go through simple growth in their understanding or more radical restructuring of their conceptual ecology. Conceptual ecology, originating with Toulmin's (1972) description of conceptual development within an "intellectual ecology," refers to the dynamic conceptual context in which learners base growth or change in their beliefs about the world (Duit & Treagust, 1998; Posner et al., 1982; Strike & Posner, 1992). Duit and Treagust (1995) referred to these two types of learning as *conceptual growth* and *conceptual change* (others, such as Vosniadou (1994) have included all of these changes under the heading of *conceptual change*, separating out *enrichment* from *revision* in a similar dichotomy). Conceptual growth is the addition of new information to existing conceptual structures in such a way that previously held knowledge and connections are mostly unmodified. Conceptual change refers then to changes in understanding that requires reorganization of existing conceptual structures and new connections between previously existing ideas. Both conceptual change and conceptual growth are important for moving towards scientific understanding, however in the limited time frame of this instructional intervention, growth in the children's conceptual structures may be a more realistic expectation.

We do not suppose that the children will obtain a full scientific understanding because this instruction does not address all aspects of their underlying conceptual ecology (specifically, the explanations for apparent motions). Young children's non-normative ideas may not be deeply held beliefs about the world; rather they may be produced on the spot as the result of other more deeply held beliefs that are part of their conceptual ecology (Strike & Posner, 1992). Strike and Posner suggest that for areas of *weak conceptualization*, it may be more important to address the ways that the learner's misconception is connected within their conceptual ecology. Some areas of apparent celestial motion are likely to be weakly conceptualized, though they may be based on more firmly held beliefs about the world (Vosniadou, 2003; Vosniadou & Brewer, 1994). Vosniadou and her colleagues' research suggest that children hold firm beliefs about the earth's shape and the nature of the sun, moon and stars. Thus while young children may believe that the earth is flat and at the "bottom" of the cosmos and that the sun goes up and down each day, their visualization of that motion may be weakly conceptualized and more receptive to change than their understanding of the earth's shape (Nussbaum, 1979). Similarly, children may strongly hold the belief that the moon moves up in the evening and down at the end of night, but weakly conceptualize the details of that motion or if it is continuous. Despite being weakly conceptualized, it may be that improved understanding in these areas has the potential to provide a reason to re-evaluate other concepts and explanations.

### *Dual Coding Theory and the Importance of Imagery*

Experts describing apparent celestial motion are able to conjure clear mental images of these motions, such as the image of the sun rising and setting or the changing appearance of the moon. Instruction that increases children's repertoire of mental representations in the visual mode may help them develop a more robust understanding of apparent celestial motion. The planetarium allows students to view celestial motion in a way that they are unable to do on their own because the planetarium instrument is able to project a days worth or even a years worth of motion in a matter of a few minutes. Thus, a key feature of planetarium instruction is how it can be used to help students visualize representations of celestial phenomena.

Previous research on the relationship between verbal information and visual imagery has demonstrated the powerful importance of how students make connections between concepts and images and is potentially useful in interpreting the benefit of instruction in the planetarium. Dual Coding Theory suggests that human behavior and experience can be explained "in terms of dynamic associative processes that operate on a rich network of modality-specific verbal and nonverbal (or imagery) representations'' (Clark & Paivio, 1991, p. 149). Both the verbal and nonverbal systems consist of separate subsystems, capable of functioning independently (Paivio, 1986). The nonverbal subsystems correspond to different sensory modalities (visual, auditory, haptic, and kinesthetic) that form an integrated whole by the connections between these subsystems. The connections that link verbal and nonverbal representations in a complex association may allow words to trigger potentially more complex and useful nonverbal mental representations.

This way of understanding the verbal and nonverbal symbolic systems also suggests that successful instruction helps students form the structural connections between various representations so that students can trigger the appropriate mental representation (verbal, auditory, or kinesthetic) for future related activities (Clark & Paivio, 1991). Children interacting with the images displayed in a planetarium have the opportunity to make new connections in their knowledge structure using images of celestial motion and connecting those images to such verbal codes as ''the rising and setting of the sun'' or ''the stars apparent motion during the night.''

### *Kinesthetic Learning Techniques*

Students were engaged with the concepts in the planetarium program through the use of kinesthetic learning techniques (KLTs): students using their own motions of their own bodies to connect with the target concepts. Though limited research on kinesthetic learning exists, KLTs have the potential to actively engage participants in developing knowledge of specific concepts, especially those that involve motion and perspective. Conceptual change theory informed the ways that KLTs were included in the program to promote learning through interest, activation of prior knowledge, and implementation of cognitive conflict and resolution. KLTs' impact on student learning can also be explained using Dual Coding Theory. KLTs form the foundation of the instructional design as they tie together the theoretical model of learning in the planetarium with the conceptual area of celestial motion.

For conceptual growth to occur, learners must bring their prior knowledge of the conceptual area to the forefront. KLTs can be used to do this by asking children to use their own motions to describe their personal understanding of the sun, moon and stars' patterns of motion with their hands and arms as they pretend to trace patterns on the dome of the planetarium. Successful instruction also encourages self-regulation and purposeful engagement in learning (Vosniadou, 2003; White & Fredricksen, 2000). KLTs can be used to encourage this level of purposeful engagement by asking students to compare their initial ideas to patterns of motion that they observed as they first make predictions by pointing or tracing imaginary paths and then follow and mimic the paths of celestial objects, as demonstrated in the planetarium. A recent study of an instructional intervention on the seasons with high school students suggests that kinesthetic engagement produces a positive affective response among learners (Slater, Morrow, & Slater, 2008). Further, KLTs can be used to engage all of the students, regardless of their ability to verbally articulate their ideas.

Students who are engaged in mimicking the motion are processing what they are observing across both kinesthetic and visual modalities. Dual Coding Theory suggests that some of the power of kinesthetic learning may lie in connecting kinesthetic ''imagery'' to the verbal and visual codes for that concept (Clark & Paivio, 1991). Through the use of KLTs, students can build their repertoire of kinesthetic images that may help them describe apparent celestial motion and use these concepts in future problem-solving scenarios. By studying these concepts in the planetarium, the students are learning verbal, visual, and kinesthetic representations simultaneously and thus forming a network of connected mental imagery and verbal codes that may be accessed at a later time. Dual Coding Theory also suggests that each system (verbal, visual, and kinesthetic) undergoes separate processing. Instruction that is designed to take advantage of the processing of different modalities may help students learn these concepts because the new ideas will be encoded in multiple ways.

## Research Questions

The purpose of this study is to investigate changes in early elementary-aged students' descriptions of the patterns of apparent motions of the sun, moon and stars through planetarium-based instruction using KLTs. Six key ideas of celestial motion were covered in the program using KLTs: path of the sun in summer, path of the sun in winter, comparison of the path of sun in summer and winter, path of the moon across the sky, the motion of the stars, and what happens to cause daytime. Three additional subjects were covered during the program that did not include corresponding KLTs: changing appearance of the moon, appearance of the moon during daytime, and location of the stars during the daytime. The following research questions guided this study:

1. Do students who participate in a planetarium program that utilizes kinesthetic learning techniques (KLTs) improve their descriptions of the patterns of motion of celestial objects?
2. Do students who participate in planetarium program that utilizes KLTs improve their conceptions of additional topics covered in the planetarium program that were not taught by KLTs?

## Methodology

### *Participants*

Seven teachers of first and second grade agreed to allow their students to participate. Four classes were a combination of first and second grade students from Allensville Elementary school in a small Midwestern city containing a university (all personal names and places are pseudonyms). The other three classes were second grade students from Adventure Elementary School, located in a large town about 30 miles from Allensville. The majority of students in the study had previously attended at least one planetarium program prior to this study.

Ten students from each classroom were randomly selected or selected by the teacher (chosen for a range in abilities) to be interviewed (split evenly by gender). Attrition resulted in a total of 63 students being interviewed before and after the planetarium visit. Sixteen students were in first grade (7 female, 9 male). Forty-seven students were in second grade (23 female, 24 male). Students ranged in age from 6.4 to 8.8 years old with an average age of 7.6 years.

### *Instruction in the Planetarium*

Students participated in a 45-minute live program at a small planetarium located in a natural history museum. Each of the seven classes attended the program separately. The program was taught by the author of this study (11 years of planetarium experience). All of the patterns of motion (except the changing phases of the moon) were taught by combining students' kinesthetic actions and visual observation with the instructor's verbal descriptions to encourage student engagement and coding in multiple modalities. The following describes the basic content of the planetarium program and how KLTs were associated with each of the major apparent motion concepts.

*The Apparent Motion of the Sun on the First Day of Summer.* Students were asked to verbally respond to questions about the sun's location in the morning and then to predict the apparent motion of the sun during the day by pointing with their hands and arms then tracing out the motion across the sky. Students then pointed to the planetarium's sun-image and kinesthetically followed the accurate depiction of the motion as the machine moved the image across the dome, experiencing the concept both visually and kinesthetically. This was done to encourage the children to learn that the sun rises and sets on opposite sides of the sky and moves in a continuous fashion. These are concepts commonly not understood by early elementary children (Plummer, in press).

*The Apparent Motion of the Stars.* After the sunset, the planetarium became dark and the students observed the rising and setting motion of the stars. Students were asked to point to the direction where new stars were rising and to the direction where other stars were setting. Students then picked a star and traced its motion across the sky. These activities helped the children understand that the stars rise and set like the sun does, through visual and kinesthetic experiences. This contradicts many children's belief that the stars do not appear to move during the night (Plummer, in press). At the end of the night, students were asked to point to where they expected to see the sunrise.

*The Apparent Motion of the Sun in Summer.* Students again traced the motion of the sun as it rose in the northeast. The motion was stopped when the sun reached its highest position, at noon, in the south. The students pointed to the sun's location and then pointed to the zenith to emphasize the difference, that the sun is not directly overhead in summer. The students then predicted where the sun will be in the afternoon and where it will set by pointing. As the projector resumed spinning, the children traced the motion of the sun as they observed it to set in the northwest.

*The Apparent Motion of the Stars.* The instructor pointed out several constellations and bright stars. The instructor explained to the children that they would participate in a game where they would see which star stays up the longest and which sets first. The students then pointed to and followed a star of their choice as the projector showed the progression of the night, until the sun rose again. The instructor asked the children to say which stars were still up and which had set. The purpose of this game was to help the children see that stars appear to move during the night as some rise and others set, concepts not understood by most adults and children.

*The Apparent Motion of the Moon.* The orbit of the moon was demonstrated with physical models as the instructor explained that this happens once every 28 days. All students pretended to be the earth by standing up and slowly spinning to show that sometimes our side of the earth faces the moon and other times it does not. The students then sat down and predicted, by pointing, where they would see the moon when it rises. They watched as the crescent moon rose, just after the sun, as the instructor verbally indicated that the moon can be seen during the daytime. The students were asked to predict the apparent motion of the moon. They were asked to point to both the sun and moon at the same time and follow their motion while taking the same path across the sky. After the sun and moon set, the students were told that they were going to see what the moon will look like in 3 days and asked to predict where it will rise. The students watched as the sun rose, and then later, the first quarter moon rose. As they watched the moon appear to move across the sky, the students were asked if its appearance changed significantly as it moved across the sky, to emphasize that the moon's appearance does not change significantly during a single day. This procedure was repeated for the full moon phase.

*The Apparent Motion of the Sun in Winter.* Students were asked to point to the position where the sun rose in summer and then to where they saw it rising in winter. After following the sun's rising motion, they also pointed to where the sun is highest in winter and then compared that to its altitude at noon in summer. The students were asked if they saw the sun directly overhead during the presentation. After following the sun's motion to sunset, the children were asked to compare the sun's path in summer and in winter, to emphasize that the path is lower and shorter in winter.

### *Data Collection*

The topics covered in the interview were selected primarily based on the astronomy topics found in *NSES* and *Benchmarks* for early elementary grades. The interview design used for this study has been previously described in Plummer (in press). Categories used to develop the interview questions are listed in Table 1. Associated interview questions are listed in the Appendix. Interviews were conducted one-on-one with participants at their schools. Students were interviewed in a dome that resembled a very small planetarium (the structure was 6 feet high with a 4 foot diameter dome) to model the actual sky in three dimensions. The students used a small flashlight to demonstrate their ideas about the apparent motion of the sun, moon, and stars on the interior ceiling of the dome.

Audio of each interview was digitally recorded. Visual information from the students' demonstrations using the flashlight was drawn by the interviewer on a template representing the dome. Diagrams were made for each student's answers about the path of the sun in summer and in winter, the path of the moon, and the motion of the stars. The combination of these diagrams and audio recordings were later used to code each student's level of understanding for each topic. The mean length of time between the planetarium program and the initial interview was 9.0 days (SD = 3.5) and the final interview was 6.9 days (SD = 1.9). The mean length of the pre-interview was 12.0 minutes (SD = 3.1) and the post-interview was 10.5 minutes (SD = 2.4).

Table 1
*Celestial motion categories*

| Category | Description |
|---|---|
| Spath | Is the path of the sun in Summer accurate? |
| Szen | Is the sun below the zenith at its highest point in Summer? |
| Wpath | Is the path of the sun in Winter accurate? |
| Wzen | Is the sun below the zenith at its highest point in Winter? |
| Clen | Is the length of the sun's path shorter in winter compared to summer? |
| Calt | Is the sun's altitude lower in winter compared to summer? |
| Mapp | Does the appearance of the moon change on the order of days or up to a month? |
| Mcn | Does the shape of the moon appear to change over the course of one night? |
| Mday | Is the moon ever visible during the daytime? |
| Mpath | Is the path of the moon accurate? |
| Stmv | Do the stars appear to move at night? |
| Stdif | Do we see different stars during the night? |
| Stday | Where are the stars during the daytime? |
| SunD | What happens to make it daytime? |

### *Data Analysis*

Codes were developed for each category representing the variety of concepts expressed by students during the interviews. (For a full description of all codes see Plummer (in press)). These codes were then grouped into levels of accuracy: accurate, partially accurate, or non-normative. This was done in order to assign a numeric value to each student's level of understanding for statistical analysis, allowing the students' responses to be represented by numbers: accurate was designated as "3," partially accurate as "2" and non-normative as "1." Inter-rater agreement was calculated between the two coders by computing the ratio of agreements to the total number of categories. There was a 92% agreement between the two raters.

The Wilcoxon matched-pairs signed-ranks test was used to determine whether the distribution of scores from the pre- and post-instruction interview results for each student were significantly different. The Wilcoxon test gives more weight to students who improved from non-normative to accurate than non-normative to partially accurate. Because the Wilcoxon test only compares the students who improved to those who regressed, the analysis below also considers the full distribution of changes in students' responses across the entire group of students tested.

Student characteristics were examined for possible confounding variables: initial knowledge level, gender, grade level, and school. Students' initial knowledge level was compared with improvement for each category using the Mann–Whitney *U*-test for non-parametric data to determine whether the planetarium program was more or less helpful for students with non-normative understanding compared to partially accurate. The focus of this analysis was the tendency to improve, not the magnitude of improvement. To do this, improvement was set to equal to "1," no change equal to "0" and regression equal to "−1." The Mann–Whitney *U*-test was also used to determine whether gender, grade level, or school was correlated with either the initial knowledge level or with improvement for each category using the same improvement levels as defined above.

## Findings

### *Topics Supported By Kinesthetic Learning Techniques*

The statistical analysis comparing students' pre- and post-visit answers for each category shows significant improvement for all topics supported by kinesthetic learning techniques (Table 2). The first column of Table 2 indicates the category; the first 10 rows are categories supported by KLTs. The next three columns of Table 2 show the number of students who improved, regressed, or stayed at the same accuracy level, respectively. The fifth column shows the results of the Wilcoxon Test. The sixth, seventh and eighth columns show the number of students, post-instruction, at each accuracy level followed by the number of students at that level who improved into that accuracy level, stayed in the same level, or regressed into that

Table 2
*Results of Wilcoxon test and the number of students by accuracy level after instruction for each category*

| Category | Improved | Regressed | No change | Wilcoxon *Z* | Post-instruction accuracy level[a] | | |
|---|---|---|---|---|---|---|---|
| | | | | | 1 | 2 | 3 |
| Spath | 39 (61.9%) | 1 (1.6%) | 23 (36.5%) | $-5.72^{***}$ | 9 (0, 9, 0)[b] | 20 (5, 14, 1)[b] | 34 (34, 0, 0)[b] |
| Szen | 41 (65%) | 3 (4.8%) | 19 (30.2%) | $-5.54^{***}$ | 12 (0, 11, 1) | 15 (8, 5, 2) | 36 (33, 3, 0) |
| Wpath | 42 (66.7%) | 1 (1.6%) | 20 (31.7%) | $-5.87^{***}$ | 9 (0, 8, 1) | 16 (6, 10, 0) | 38 (36, 2, 0) |
| Wzen | 42 (66.7%) | 1 (1.6%) | 20 (31.7%) | $-5.89^{***}$ | 5 (0, 5, 0) | 7 (4, 2, 1) | 51 (39, 12, 0) |
| Clen | 34 (54.0%) | 2 (3.2%) | 27 (42.9%) | $-5.33^{***}$ | 25 (0, 24, 1) | — | 38 (35, 3, 0) |
| Calt | 35 (55.6%) | 4 (6.3%) | 24 (38.1%) | $-4.46^{***}$ | 17 (0, 14, 3) | 6 (4, 1, 1) | 40 (31, 9, 0) |
| Mpath | 34 (54.0%) | 5 (7.9%) | 24 (38.1%) | $-4.63^{***}$ | 12 (0,10, 2) | 16 (2, 11, 3) | 35 (32, 3, 0) |
| Stmv | 26 (41.3%) | 2 (3.2%) | 35 (55.6%) | $-4.11^{***}$ | 17 (0,15,2) | 7 (5, 2, 0) | 39 (21,18,0) |
| Stdif | 30 (47.6%) | 2 (3.2%) | 31 (49.2%) | $-4.78^{***}$ | 21 (0, 20, 1) | 15 (9, 5, 1) | 27 (21, 6, 0) |
| SunD[c,d] | 18 (29%) | 9 (16%) | 35 (56%) | $-2.53^{*}$ | 21 (0, 16, 5) | 24 (11, 9, 4) | 17 (9, 8, 0) |
| Mapp[c] | 20 (32%) | 2 (3%) | 40 (65%) | $-3.84^{***}$ | 21 (0, 19, 2) | — | 41 (20, 21, 0) |
| Mcn[c] | 15 (26%) | 1 (2%) | 42 (72%) | $-3.50^{***}$ | 16 (0,15,1) | — | 42 (15, 27, 0) |
| Mday | 13 (20.6%) | 3 (4.8%) | 47 (74.6%) | $-2.48^{*}$ | 3 (0, 2, 1) | 2 (0, 0, 2) | 58 (13, 45, 0) |
| Stday | 19 (30%) | 2 (3%) | 42 (67%) | $-3.50^{***}$ | 10 (0, 8, 2) | 3 (1, 2, 0) | 50 (18, 32, 0) |

$^{*}p < 0.05$.
$^{***}p < 0.001$
[a]1 = non-normative, 2 = partially accurate, 3 = accurate.
[b]Explanation of each number: Total number of students at this level (number of students who improved into this level, number of students who remained the same, number of students who regressed into this level).
[c]Some students were not asked this question during one of their interviews.
[d]1 = non-normative; 2 = the sun rises; 3 = earth turns around to face the sun.

level. This is useful for examining which concepts had a large number of students who were accurate prior to instruction and thus did not change due to ceiling effects (such as Mday—45 students already knew that we can see the moon during the day, before the planetarium program, and did not change this accurate concept after the program).

### *Analysis of Correlations Between Student Characteristics and Improvement*

Initial knowledge of celestial motion, gender, grade level, and school were analyzed as possible confounding factors with the level of improvement. Five representative categories covering the range of concepts were examined: the path of the sun in summer (Spath), the path of the sun in winter (Wpath), comparison of the length of the sun's path (Clen), the path of the moon (Mpath), the motion of the stars (Stmv), and the different stars throughout the night (Stdif). Analysis found no significant difference in student improvement after the planetarium program when comparing students who began as non-normative to those who started as partially accurate for all five topics.

Gender, grade level, and school were analyzed for correlation with either the initial accuracy or with improvement after the planetarium program. Grade level was only a factor in improvement for the first grade students, who were significantly less accurate in their initial description of the winter sun's path (Wpath) than the second grade students (Mann–Whitney $U = 269.5$, $Z$ $(N = 63) = -1.97$, $p < 0.05$). Gender was only found to be related to knowledge of different stars throughout the night (Stdif); girls showed significant improvement compared to the boys after the planetarium program (Mann–Whitney $U = 366$, $Z$ $(N = 63) = -2.02$, $p < 0.05$). School was only a factor in predicting initial accuracy of the apparent motion of the stars; students from Allensville Elementary School had a more accurate understanding compared to students from Adventure (Mann–Whitney $U = 366$, $Z$ $(N = 63) = -2.56$, $p < 0.05$). Overall, there were only isolated differences between the schools, between grades, and between genders suggesting that these factors did not have a significant influence.

### *The Apparent Motion of the Sun in Summer*

Students showed significant improvement on their ability to demonstrate the accurate path of the sun after the planetarium program ($Z = -5.72$, $p < 0.001$). Of the twenty students (32%) who demonstrated non-normative ideas prior to the program, 10 students improved to either partially accurate (4 students) or accurate (6 students). Two-thirds of the students (67%) initially indicated that the sun's path is a straight line across the sky, through the zenith, rising and setting 180° apart (partially accurate). After the planetarium visit, 67% of those students improved to an accurate demonstration of the sun's path, while only 33% retained the same partially accurate concept. Much of the improvement in the student's description of the path of the sun was through learning that even in summer the sun is never overhead in their city, which was a significant improvement in the students' description of the sun's highest altitude in the summer ($Z = -5.54$, $p < 0.001$). This suggests that by tracing the sun's motion across the planetarium dome and comparing the sun's highest altitude with the zenith is an effective way of learning that the sun does not pass directly overhead.

### *The Apparent Motion of the Sun in Winter*

There was significant improvement in the students' description of the sun's path in winter ($Z = -5.87$, $p < 0.001$). Sixty-five percent of the students who demonstrated non-normative paths during their pre-instruction interview improved to an accurate (nine students) or partially accurate path (six students). Of those six students who, in their post-instruction interview, demonstrated partially accurate paths, three demonstrated both a non-normative path (when asked to point to the sun's position at specific times of day) and then accurate path (when asked to show the entire path). Perhaps these students were still working through the ideas in the post-interview or had difficulty connecting the sun's location to specific times of the day. The number of students who accurately expressed that the sun's path passes below the zenith in the winter improved significantly, from 20% to 81% ($Z = -5.95$, $p < 0.001$).

### *Comparison of the Sun's Path Between Summer and Winter*

For an accurate comparison of the sun's path across seasons, a student needed to show (a) at least a 45° difference in the rising and setting positions in summer compared to winter, and (b) that the sun reaches a higher altitude in summer compared to winter. The coding did not take into consideration the directions of these motions or the angle of the sun's path. The students showed significant improvement in how they expressed differences in seasonal change ($Z = -5.33$, $p < 0.001$). Before instruction, only four students demonstrated paths that correctly compared the sun's path across the seasons. Fifty-nine percent of initially inaccurate students (35 students) improved to give an accurate comparison. Accuracy in the comparison of the sun's path in summer and winter was primarily a result of increased accuracy in how the students compared the noontime altitude of the sun, which increased from 21% in pre-interviews to 63% in post-interviews ($Z = -4.46$, $p < 0.001$).

### *The Apparent Motion of the Moon*

Similar to the path of the sun, the students were coded as accurate if their path for the moon was a smooth curve across the sky that does not pass through the zenith and partially accurate if it did. There was also a large range of non-normative ideas concerning the apparent motion of the moon including: the moon circles around the sky without rising or setting, the moon rises/sets in the same location, and that the moon does not move during the night. The students showed significant improvement in their description of the path of the moon after attending the planetarium program ($Z = -4.63$, $p < 0.001$). For example, Jon improved from a non-normative to an accurate description. Before the planetarium, he was not sure how to describe the motion of the moon: "Usually the moon I don't think it changes position. Every night I think it changes. But usually it's right around here. In the middle." After the planetarium program he was able to demonstrate the path of the moon as a smooth curve across the sky and indicated that "it would be ⟨*⟩ the same thing as the sun" (⟨*⟩ indicates an inaudible word or phrase).

*The Apparent Motion of the Stars*

Apparent stellar motion may have been the most challenging topic for the students. In their pre-instruction interviews, six students simply said that they did not know rather than giving an answer. The post-instruction comparison revealed a significant improvement in how students described the motion of stars (Stmv; $Z = -4.11$, $p < 0.001$), as well as a significant improvement in the conceptual area of different stars throughout the night (Stdif; $Z = -4.78$, $p < 0.001$).

Most of the improvement was from non-normative students who did not think that the stars moved to either a partially accurate (demonstrating some understanding that the stars move) or accurate concept (demonstrating the stars moving across the sky in a smooth path, though not necessarily the full motion of rising and setting). Fifty-six percent of the students who began as non-normative (19 of 34 students) improved to partially accurate or accurate after planetarium instruction. Seventy percent of the students (7 of 10 students) with initial partially accurate understandings improved to accurate understanding in the post-visit interview.

Andy, a second grade student, initially had very little understanding of motion of the stars but improved to a more accurate understanding after the planetarium program. The following excerpt is from his pre-interview (interview quotes are slightly edited to improve readability):

I: Do the stars move in the sky at night?

Andy: Well, someone told me that the stars were little planets but they're like, like things that they can't land on.

I: Let's pretend that the flashlight's a bright star... Let's say you see it there just after sunset when it gets dark out. Where will that star be at midnight?

Andy: I think it would be just like there ⟨*⟩.

I: So would it stay in the same place?

Andy: Yes.

I: Do we see the same stars in the sky all night long?

Andy: I don't know 'cause I'm still asleep at midnight.

I: That's a good point. What happens to the stars at the end of the night when the sun comes up?

Andy: I kind of see a little bit in the morning but when it gets towards the afternoon the stars fade away and go down.

I: Are there still stars up there in the sky during the daytime?

Andy: Uhm, I don't know. I don't really see stars ⟨*⟩. I don't think there is stars.

In his post-visit interview, Andy brought up the stars while answering questions about the moon. He begins by describing the moon's motion in winter:

Andy: Like that and then all the stars are following it ⟨*⟩.

I: So the moon goes up and then it goes down. And the stars do the same thing?

Andy: Yes.

I: What does the moon do in the summertime?

Andy: That (showing the motion) and the stars are doing the same thing but it last long and ⟨*⟩ longer and longer, and longer, gets lower.

I: Does the moon always go down when the sun comes up?

Andy: Well, the moon would going down, the stars are following with it. And moving like that and the stars are doing it with it but the sun does the same things it do. But the sun is going slower than the moon. So when the moon goes down the sun was popping up in right there.

I: Do we see the same stars in the sky all night long?

Andy: Well, some of the stars aren't going down ⟨*⟩ because the uhm, uhm, what's that one star called, the heart?

I: Oh – the heart, Antares the heart of the Scorpion.

Andy: Yeah, it stays up longer.

I: So do the stars rise and set like the sun does?

Andy: Yeah. They come down eventually.

While containing some inaccuracies in the details, Andy does show improvement in his understanding of the apparent motion of the stars.

Twenty-two percent of the students held onto their initial beliefs: that the stars do not move and that we do not see different stars throughout the night. Not all of the students who improved their description of the stars' motion also learned that we see different stars throughout the night (11% remained non-normative).

*What Happens to Make it Daytime?*

One accurate way of describing what happens to make it daytime is to show the sun rising. However, the scientifically correct explanation would also include explaining that the earth rotates to face the sun. Because the planetarium program was designed to promote the apparent motion of the sun, not the actual motion of the earth, it may be reasonable to suggest that the majority of improvement was in students' learning to describe the apparent motion, not explain using the rotation. To test this hypothesis, these two accurate responses were assigned the values 2 (accurate) to ''the sun rises'' and 3 (more accurate) to ''the earth turns around to face the sun'' (shown in Table 2). There was a significant improvement in student responses (SunD; $Z = -2.53$, $p < 0.02$), with students improving to each type of response. Before the planetarium program, half of the students interviewed (50%) had non-normative ideas about what happens to make it daytime. After the planetarium program, nearly a third of those students (29%) changed their answer to say that the sunrises while only 10% changed to say that the earth rotates to face the sun in the morning, suggesting that the planetarium program was more successful in promoting the description of the sun's apparent motion than the earth's rotation.

Marshall (second grade) changed from a non-normative response to explaining daytime with the sun rising. Before the planetarium program, he said that to make it daytime again, ''the moon would have to turn around 'cause usually we don't see a crescent moon in the morning. And then the sun would go down a little bit so then we could see the sun.'' After the planetarium program he responded, ''well, the sun would kinda appear [points to horizon] and rise up and do its normal thing and ⟨*⟩ . . . kinda disappears when it goes down [he demonstrates the entire path of the sun.]''

Ariana (second grade) shifts from a non-normative understanding to a clear description of the earth's rotation. In her pre-instruction interview she describes the motion as the sun actually moving to the other side of the earth:

I: Where is the sun at night when we can't see it?
Ariana: It's over on the other side of the earth.
I: What is going to happen to make it daytime again?
Ariana: It will come back around then be up.

After the planetarium program her responses use the rotation of the earth:

I: At nighttime, when we can't see the sun, where is the sun?
Ariana: Other side of the earth. Well it doesn't move but the earth moves and then it's on the dark side. Our side. So like if the sun is right there and the earth, if it's night time our side will be facing that way so there's no sun but . . . [During this she is using her hand to show the rotation of the earth.] So we're facing away from the sun. Yeah.
I: And then to make it daytime again what happens?
Ariana: It spins around again and we see the sun again.

*Additional Topics Not Supported By Kinesthetic Learning Techniques*

Significant improvement was found comparing pre- to post-instruction interviews for all four categories under the second research question relating to topics covered during the planetarium program that were not taught using KLTs (see Table 2).

*Analysis of Correlations Between Student Characteristics and Improvement*

Prior knowledge had no effect on whether or not the students learned that the moon appears in the daytime sky (Mday; Mann–Whitney $U$ ($N = 15$) $= 21.0$, $Z = -1.20$, $p > 0.05$). The correlation between initial knowledge and improvement was not analyzed for the moon's changing appearance, and the stars' location during the day (Mapp, Mcn, and Stday) because less than five students were coded as partially accurate in each category.

Gender, grade level, and school were not found to be a significant factor in predicting initial accuracy or improvement except in one case. Students from Adventure were significantly more likely to improve their knowledge of the moon's visibility in the daytime (Mday) compared to the students from Allensville (Mann–Whitney $U$ ($N = 63$) $= 341.0$, $Z = -2.60$, $p = 0.01$). However, this represents a small portion of the students; only 25% of the students gave answers that improved or regressed.

*Length of Time for the Appearance of the Moon to Change*

There was a significant improvement in the number of students who indicated the accurate length of time for the appearance of the moon to change (Mapp, $Z = -3.84$, $p < 0.001$). The students were either coded as accurate (the phase of the moon changes between more than a night and no more than a month), or inaccurate (the phase of the moon changes in less than a night or more than a month). The number of students who gave an accurate response doubled after attending the planetarium program.

The students were also asked if they thought the shape of the moon would appear to change during a single night. Students were coded as accurate if they said that the appearance of the moon would not change at all or not change enough for us to notice during the night (this was asked with reference to drawings they made of different phases of the moon so the emphasis was on significant change in the shape, such as from crescent to half). There was significant improvement in students' answers after attending the planetarium program (Mcn; $Z = -3.50$, $p < 0.001$). Fifty percent of those students who began as non-normative (15 students) improved to an accurate response.

*Location of the Moon During the Day*

The students were asked whether or not the moon can be seen during the daytime. The students were coded as inaccurate if they said "No" we cannot see the moon during the day and accurate if they said "Yes" we can see the moon during the day. Students who said "No," then paused and changed their answer to indicate that sometimes you could see the moon were coded as partially accurate. These students seem to have some level of confusion of this subject as if two concepts are in conflict for them—the idea that the moon is up only at night and that perhaps they have actually seen the moon during the daytime. There was a statistically significant improvement in the students' understanding of this concept as seen by the number of students who improved compared to those who regressed after the planetarium program (Mday; $Z = -2.48$, $p < 0.05$). Though the majority of the students initially knew that the moon is visible during the daytime sky (76%), after the planetarium program all but two of the students were accurate (92%).

*Location of the Stars During the Day*

During the planetarium program, the students were able to see the stars both during the simulated "daytime" and "nighttime" because the lights used to make the sky appear daytime blue were not bright enough to drown out the projected stars. During the program, we talked about why we cannot see the stars in the real daytime sky compared to the planetarium sky. The students were also able to observe that the stars seem to move across the sky during the night and then to continue to rise and set during the day. During the interviews, the students were asked "What happens to the stars when the sun comes up?" A student coded as accurate indicated that the stars are still in the sky during the day, such as Faith's post-instruction response: "Well it's too bright to see them. They're still there but you just can't see them." A few students who said that the stars are still in the sky were coded as partially accurate because they gave an inaccurate explanation, such indicating clouds are the reason we cannot see the stars during the day. Accurate responses to this question increased from 54% before the planetarium program to 79% after the planetarium program (Stday; $Z = -3.50$, $p < 0.001$).

## Conclusion and Implications

The significant improvement in how the first and second grade students' described apparent celestial motion indicates that young children are capable of learning to describe these patterns of motion and supports the placement of these concepts at the early elementary level in the *NSES* and *Benchmarks*. The students showed the most improvement on the topics relating to the sun and the moon's apparent motion with more than half of the students giving more accurate descriptions of the patterns of motion of these objects. Areas that showed the least improvement included the change in the sun's path over the seasons and the motion of the stars. Learning to correctly compare the sun's path across seasons requires keeping track of a complex set of differences (such as the rise/set positions and the change in the noon-time altitude). Perhaps conceptual growth was limited because this combination of changes to the sun's path is too complex given that many students were not initially able to give an accurate description of the sun's path.

*Benchmarks* place the apparent motion of the stars at the grades 3–5 level which is consistent with the findings of this study; fewer students improved their descriptions of the stars' motion compared to the sun and moon. Children are likely to have less prior knowledge about the stars based on their own observations, compared to the sun and moon. Brief observations of the night sky combined with the complexity involved in recognizing individual stars or patterns of stars may have contributed to the development of beliefs that conflicted with the planetarium observations, such as "the stars are fixed and never move." These children may have found the idea that the stars appear to move smoothly throughout the night to be too incongruent with their initial beliefs to accept. Without knowledge of why the stars appear to move (the rotation of the earth), the pattern of the stars' apparent motion may not make sense to the students and thus limit conceptual growth in this area. Improvement in the concept of the stars' apparent celestial motion may be more successful after children have more experience using the earth's rotation to explain the sun and moon's motion or with instruction that spends longer time on this conceptual area.

The purpose of investigating a single planetarium intervention was to uncover the ways this program can improve children's descriptions of apparent celestial motion with the intention that this instruction could then be used in concert with classroom instruction on these topics. Most children experience planetarium visits as fieldtrips, not as a consistent learning environment. Children were interviewed an average of one week after the program, which suggests that if teachers return to these topics within a week of their students' visit to a planetarium program of this nature that many of the children will have retained their new understanding of the sky and have those concepts and descriptions available for other astronomy activities that would extend their knowledge. The success of this form of instruction in improving children's observational knowledge is encouraging for the use in future instruction that makes connections between the observed patterns of celestial motion and the explanations of those motions.

Prior to the planetarium program, the children's understanding of the patterns of celestial motion were based on their ontological beliefs about the sun, moon and stars, their relation to the earth, and limited observational experiences (Plummer, in press; Nussbaum & Novak, 1976; Vosniadou & Brewer, 1992, 1994; Sharp, 1996). The significant improvement found in the number of students giving more accurate descriptions of apparent celestial motion can be explained through the ways instruction promoted conceptual growth and engaged students across multiple modalities. Children were encouraged to make predictions based on their prior knowledge and both visual and verbal prompts may have stimulated their prior experiences with these concepts. The ways that children were asked to interact kinesthetically and visually with the planetarium program was based on knowledge of common alternative conceptions in apparent celestial motion (Plummer, in press). Students with a weakly developed understanding of the patterns of celestial motion prior to instruction may have improved because the program provided them with a way to describe and visualize these motions that built on some of their prior concepts without radically reorganizing their prior knowledge. For students with more clearly defined mental images of the patterns of apparent celestial motion, conceptual growth may have occurred because KLTs, in combination with their observations, provided a clear and plausible alternative to their previous description. The use of kinesthetic-cognitive conflict, kinesthetic experiences that contradict prior knowledge, may have been a factor in improving these children's descriptions (Druyan, 1997). When successful, students recognize a conflict in their present description of the patterns of motion with the visualization presented in the planetarium and choose to add the new description to their conceptual ecology.

Some of the power of using one's own kinesthetic actions to learn may derive from students encoding information in multiple modalities (Clark & Paivio, 1991; Paivio, 1986). During the program, students associated their memory of the motions they performed with the verbal codes for apparent celestial motion and the visual images observed. Thus, conceptual growth could be the result of a combination of sensory, visual, and auditory stimuli. Previous studies have also suggested that students show improvement via the dual coding of kinesthetic and visual or auditory stimuli in studies about length, balance, and speed (Druyan, 1997) and in nanoscale science using haptic feedback with computer visualizations (Jones, Minogue, Tretter, Nigishi, & Taylor, 2006). This combination of experiences may have also improved understanding because now the students are not relying on just one way of recalling when given an auditory prompt, they are relying on two: kinesthetic and visual.

The significant improvement on topics *not* covered using KLTs may be attributed both to the level of engagement in the program, encouraged by the frequent use of kinesthetic learning techniques, and the visually stimulating environment. Because the instructional setting was designed to clearly represent the real sky, this may have enhanced the students' connections to their prior experiences in observing the sun, moon, and stars. The setting may have contributed to the students' engagement in the instruction by immersing them in a three-dimensional experience. The visual experience may have allowed students to build up a repertoire of visual representations of celestial motion that can be revisited and explored when referenced at a later time. Students were often learning about non-kinesthetic concepts while simultaneously learning about KLT-related conceptions. For example, while the students followed the motion of the sun and the crescent moon's motion at the same time (by pointing at each with a different hand) they were also observing that the moon is visible in the daytime sky. Similarly, one of the concepts that many students learned during the program was that the shape of the moon does not change noticeably during 1 day's worth of apparent motion. The students observed this lack of change as they tracked with their hands and arms the moon's apparent motion in its path across the sky. And even without the use of kinesthetic imagery to improve understanding of these patterns, the students were engaged in processing the visual imagery of these topics (Clark & Paivio, 1991; Paivio, 1986). Thus, students may have been recalling these visual representations when prompted to answer questions about these concepts in the post-instruction interviews.

Though extensive research has shown that students are more likely to learn new ideas that are already aligned with their current understanding of that subject and fit into their prior knowledge (Bransford et al., 1999), in this study, no correlation was found between the students' prior knowledge and whether or not they improved. Students who had non-normative ideas about apparent celestial motion were as likely to improve as students who began as partially accurate. One possible explanation for the success of the program in both non-normative and partially accurate students requires looking at exactly what was changing between the various levels. In many topics, improving from partially accurate to accurate understanding involved learning a different idea, compared to the change from non-normative to partially accurate. For example, a child that improved from the idea that the stars do not move (non-normative) to being unable to describe the motion of the stars but knowing that they do appear to move (partially accurate) has learned a different concept than the student that starts with that same partially accurate idea and improves to an accurate demonstration of the apparent motion of the stars. Similarly, the difference between a partially accurate description of the sun and moon's paths and the accurate description was, in most cases, the location the students showed for the sun or moon's highest altitude. Students who improved learned that the sun and moon do not pass directly overhead from our latitude. Children who improved from non-normative ideas learned that the sun and moon's paths are smooth and cross the sky. The planetarium program was equally successful in teaching both of these concepts separately despite the difference in levels of prior knowledge.

This study has demonstrated one successful method for improving how elementary students describe apparent celestial motion but it also raises additional questions to be explored. Future research that compares planetarium programs with and without KLTs may allow us to more clearly state how KLTs impact learning. The longevity of the knowledge of apparent celestial motion gained by these students is also unknown. Another area which deserves more attention, both in terms of research that evaluates children's conceptions and instructional interventions, is the relation between students' understanding of apparent celestial motion and their ability to learn how to explain those motions. This level of understanding requires that students be able to move between the earth-based and the sun-centered frames of reference, in imagining these motions. By improving our understanding of the ways that children learn to move between these frames of reference and how they learn to explain apparent using actual motion, we will be better prepared to create instructional sequences that support student conceptual development in astronomy.

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## Appendix A: Interview Protocol Questions and Corresponding Categories

1. Where is the sun first thing in the morning? At 10 o'clock? At noon? In the afternoon? What happens to the sun at the end of the day? Show me again what the sun does throughout the entire day. (Summer and Winter; Spath, Wpath, Clen).
2. Where is the sun when it is highest in the sky? Is that directly overhead? (Used in both Summer and Winter; Szen and Wzen).
3. (Summer) Where is the sun when it is highest in the sky? (Winter) Where is the sun when it is highest in the sky? Is that the same as the summer? (Calt).
4. Can you draw a picture of the moon? Does the moon ever look different than that? How long does it take for the shape of the moon to change? (Mapp).
5. Does the shape of the moon change during the course of one night? (Mcn).
6. Can we ever see the moon during the day? (Mday).
7. Let's pretend that it's night. Where might we see the moon when it first gets dark out? Where would we see the moon at midnight? If we went out just before sunrise, where will the moon be? What happens to the moon when the sun comes up again? Can you show me again what the moon does during the night? (Mpath).
8. Let's pretend that it's just gotten dark outside and there is a bright star up there. Where would we see that star at midnight? Would it be in the same place? (Stmv).
9. If we went outside just before sunrise would we see the same stars as we saw just after sunset? (Stdif).
10. Why don't we see any stars during the daytime? (Stday and Stmv).
11. What is going to happen to make it daytime again? (SunD).