A Learning Progression for Celestial Motion

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Abstract: Prior research on children and adults has demonstrated that neither population hold a scientific understanding of the big ideas of astronomy, as described in standards documents for elementary science education (NRC, 1996; AAAS, 1993). This paper focuses on one set of big ideas in astronomy that are at the foundation of our understanding of the discipline: the motion of the sun, moon and stars as seen from an earth-based perspective. Lack of understanding of these big ideas may to hinder students' progress towards more advanced understanding in the domain. We have analyzed the logic of the domain and synthesized prior research that has assessed children's knowledge in this domain to develop a learning progression that describes how students' initial ideas about apparent celestial motion as they enter school can be built upon, through successively more sophisticated levels of understanding, to reach a level that aligns with the scientific view. This proposed learning progression was then used to assess the outcome of an instructional intervention in the planetarium. This paper gives a first look at the use of a learning progression framework in analyzing the structure of astronomy education. Further research is needed to clarify, elaborate, and empirically ground aspects of this learning progression that relate how children learn to describe and explain the apparent patterns of motion.

Introduction

Science is one of many areas that compete for educational time with children in school. It is therefore important for educators to identify the concepts that are central to each domain of science and build curriculum around those "big ideas." Limiting science instruction to concepts with broad explanatory power will help us weed out peripheral ideas and instruction that focuses on the rote memorization of disconnected facts. A major component of U.S. national standards (NRC, 1996; AAAS, 1993) for elementary and middle school students' astronomy goals includes understanding phenomenon that can be observed by students and explained through the unobservable motions of the earth and moon. These include the ability to explain the apparent daily motion of the sun, moon and stars, the reason for the seasons, and the phases of the moon. Central to elementary observational astronomy concepts is development of the understanding that changes in the position and appearance of celestial objects can be explained by concepts of rotation and revolution, as well as an understanding of light.

Identifying the conceptual areas that children find most challenging to learn is central to the development of a learning progression. A learning progression should be developed that is highly informed by what research has uncovered about children's naïve views of science, to constructively build on their prior knowledge of the world (Duschl, Schweingruber, & Shouse, 2007; Smith, Wiser, Anderson, & Krajcik, 2006). Research across many areas of astronomy (seasons, phases of the moon, earth shape and gravity, etc.) clearly shows that the nature of basic astronomical phenomenon is not well understood, both in terms of their observational qualities and explanatory models (e.g. Baxter, 1989; Nussbaum, 1979; Sharp, 1996; Trumper, 2001). Because children's prior knowledge does not strongly resemble the scientific concepts, early stages of a learning progression may not appear scientifically accurate. But these steps are necessary to move children along the progression.

This paper will examine the progression of understanding towards a scientific description of the apparent motion of the sun, moon and stars, focusing on grades K-8th, though this work may be extended to all learners. These concepts are an appropriate starting point for elementary students' astronomy instruction as they describe the world from the child's earth-based perspective and knowledge of these observed phenomena provide a reason for learning more advanced core concepts of rotation and revolution. Both the National Science Education Standards (*NSES;* NRC, 1996), Benchmarks for Science Literacy (*Benchmarks;* AAAS, 1993) include these concepts at the beginning of their astronomy goals.

Big ideas of apparent celestial motion

The National Science Education Standards (*NSES*; NRC, 1996) and Benchmarks for Science Literacy (AAAS, 1993; *Benchmarks*) recommend that in elementary school children should learn about the observable patterns of motion of the sun, moon and stars. All appear to move slowly across the sky with a regular pattern of motion, due to the rotation of the earth. We have also included the pattern of change in the appearance of the moon as it moves through its phases. These big ideas are based on the observable patterns of motion as opposed to the more abstract concepts that explain these motions: the rotation of the earth or the orbit of the moon.

A scientific explanation for these concepts includes understanding how our perspective changes as the earth rotates on its tilted axis while slowly orbiting the sun, and understanding how the apparent motion and appearance of the moon changes as it slowly orbits the earth once a month. Over the course of a 24-hour day, the earth's rotation causes the sun, moon and stars all appear to rise and set, with the exception of stars that continually circle around the celestial pole in the sky. In northern latitudes, the sun's path is tilted towards the south, and never passes through the zenith, the point directly over head. As the earth orbits the sun, this path shifts so that in the winter the sun's path is a short low path across the southern sky. As we move towards summer, the sun rises and sets progressively farther north while its altitude in the sky shifts higher and higher. The moon's path is similar to the sun's path across the sky. However, the moon rises and sets progressively later over the course of its 28-day cycle. During this time, the appearance of the moon changes as it moves through its phases, showing more or less of its illuminated side. The angle of the star's path across the sky is the same as the sun and moon. Over the course of the night we see stars appearing to rise in the east and set in the west. When the sun rises, the stars continue their apparent motion due to the rotating earth, but are not visible in the brightness of the daytime sky.

However, despite being "observable" in nature these concepts remain challenging for learners. Several reasons explain why these concepts are challenging to learners. The patterns of motion take place over many hours, days and even months. Recognizing the patterns of motion requires the ability to recall the location of celestial objects at a previous time and relate that location to the object's current position. These changes require that the observer be aware of the objects in the sky and capable of making those observations, which may be limited by location or weather. The fact that many of these changes are occurring at night while children sleep reduces the likelihood that the necessary observations will be made. Because of these challenges, students require instruction designed to help them make the connections between observations that will allow them to understand the patterns of motion and to accommodate these ideas with the rest of their understanding of the physical world.

Development of the learning progression

Taking Science to School, a recent report synthesizing research on children learning science, advocates the importance of concentrated, in-depth focus on big ideas in the science disciplines, leading to a call for a systematic approach towards developing learning progressions to guide future policy and curriculum reform (Duschl, Schweingruber, & Shouse, 2007). The development of a learning progression around big ideas central to each science discipline will allow curriculum developers and assessment committees to identify the ideas that lead towards the scientific understanding expected by the end of an extended instructional period, across multiple grades. This approach gives weight to the importance of extended time spent on concepts that are broadly applicable to scientific understanding.

A learning progression describes one potential pathway between the initial knowledge the children first bring to school and the end point of scientific understanding. Along this pathway, students will become more proficient, demonstrating "successively more sophisticated ways of reasoning" within that content area (Smith, Wiser, Anderson

& Krajcik, 2006, p. 3). A learning progress is designed around the big ideas of the discipline, which can be introduced in their simplest form at an early age and "progressively refined, elaborated, and extended throughout schooling" (Smith et al., 2006, p. 5). Not all students will move through this progression in the same order, nor will they all achieve the scientific understanding. Movement along a learning progression is highly dependent on the instructional interventions that students experience. Due to the lack of longitudinal studies of how children's ideas change over time when exposed to good instructional materials and methods, this learning progression is inferential. Our goal, in developing this learning progression, is to suggest how students may build upon their prior knowledge towards an expert understanding of apparent celestial motion. The learning progression is a possible description of how students may progress with good instruction.

Research on children's understanding of science is highly fragmented in most domains (Duschl, Schweingruber, & Shouse, 2007) including the concepts of astronomy explored here. The richest areas of exploration in astronomy education research have focused on how students' understanding differs from the scientific perspective, not on instructional approaches designed to improve understanding (Bailey & Slater, 2005). So, while the research on children's understanding of astronomy is limited in many areas it can begin to give us a picture of the ways to develop students' knowledge of these concepts, the particular challenges of this domain, and the research that will need to be taken in the future to refine the learning progression such that it may be used to improve student learning.

Prior work on the development of learning progressions have focused on concepts that are interdisciplinary and foundational for a broad range of topics: atomic-molecular theory (Smith, Wiser, Anderson & Krajcik, 2006) and evolution (Catley, Lehrer, & Reiser, 2005). The conceptual areas developed in this astronomy learning progression will focus on the ways we learn to describe the observed apparent motion of the sun, moon and stars. The conceptual understandings that go into a full scientific model of this system, while perhaps not having the same breadth of applicability as atomic-molecular theory and evolution, are none the less foundational for a sophisticated understanding of major concepts in observational astronomy. Much of what are considered to be important areas of astronomy for children to understand are highly contextual – primarily focusing on the specific astronomical bodies in our solar system (sun, earth, moon, and planets). This makes the study of astronomy in elementary and middle grades distinct from other areas of science.

Children's understanding of astronomy

Children's understanding of celestial motion demonstrates that their understanding may be tied to their views of the Earth. Prior research has demonstrated that children may be placed into any of a series of mental models of the shape of the earth and gravity ranging from a naïve, flat-earth view to the fully developed scientific understanding (Agan & Sneider, 2004; Bryce & Blown, 2006; Klein, 1982; Nussbaum & Novak, 1976; Nussbaum, 1979; Sneider & Ohadi, 1998; Sneider & Pulos, 1983; Vosniadou & Brewer, 1992). Students' ideas about the astronomical world are based on two fundamental pre-suppositions, with foundations in naïve physics: unsupported objects fall and the earth is flat (Vosniadou & Brewer, 1994). As children develop an understanding of the earth and cosmological objects, they may move beyond those ideas. Through cultural interventions (school, the media, books, parents, etc.) their naïve understandings of the world are modified in such ways that often keep aspects of the initial world view but add aspects of the scientific notions forming synthetic models (Vosniadou & Brewer, 1992, 1994). Children's cosmologies appear to be, for most children, robust mental models which are used to describe all related phenomena and concepts (Agan & Sneider, 2004; Bryce & Blown, 2006; Klein, 1982; Nussbaum & Novak, 1976; Nussbaum, 1979; Sneider & Ohadi, 1998; Sneider & Pulos, 1983; Vosniadou & Brewer, 1992). Some cultural variation in children's mental models of the earth and celestial objects exists, but overall the range of models is remarkably similar (Blown & Bryce 2006, Bryce & Blown, 2006; Diakidoy, Vosniadou, & Hawks, 1997; Klein, 1982; Samarapungavan, Vosniadou, & Brewer, 1996; Siegal, Butterworth, & Newcombe, 2004). Evidence across many studies using multiple interview structures (Agan & Sneider, 2004) and including longitudinal studies (Blown and Bryce; 2006) suggests that children have consistent theories about the world. Children do not go through a prescribed set of stages, but can be characterized as moving from naïve theories towards scientific theories in similar ways.

As with the earth shape and gravity notions, children's early explanations for the day-night cycle are primarily naïve and are based on their observations of the world. Most young children begin schooling with the dichotomous belief that the earth is a physical object and the sun, moon, and stars are astronomical objects. Children's understanding of the day-night phenomenon, as well as the movement of these objects, are constrained by children's beliefs about physical objects that arise from aspects of naïve physics (Diakidoy, Vosniadou, & Hawks, 1997; Samarapungavan, Vosniadou & Brewer, 1996; Vosniadou & Brewer, 1994). The prevalent notion that frames most children's naïve explanations are based on two general presuppositions: that the sun (and sometimes moon) are occluded resulting in night time darkness or that the sun moves straight up and straight down (Plummer, 2008a; Samarapungavan, et al., 1996; Vosniadou & Brewer 1994). Some of these tendencies may be shaped by a child's belief that the sun, moon and stars do not behave as inanimate object. Klein's study of Mexican-American students showed evidence of pre-causal thinking as the children described the sun as "hiding behind the mountains," "hiding behind the clouds" or "hiding behind trees" (1982, p. 105). Animistic models have also been found among Native American (Lakota/Dakota) children who suggested that "the sun and moon want to rest", "the sun is scared" at night, or referred to Lakota mythology (Diakidoy et al., 1997, p. 176).

Studies using interviewing techniques that include having children draw their ideas (American children; Vosniadou & Brewer, 1994) or use physical models (Indian children; Samarapungavan, Vosniadou, & Brewer, 1996) have found a developmental progression of children's ideas, with older students moving towards more scientific explanations for the day-night cycle. Some of this development appears to be tied to the children's developing understanding of the spherical earth model. Vosniadou and Brewer (1994) hypothesized that children must hold a spherical earth model in order to use the earth's rotation about its axis to explain the day-night cycle. Samarapungavan, Vosniadou and Brewer (1996) confirmed this prediction with their study of first and third grade children in India; children who held naïve or synthetic notions of the earth's shape did not use its rotation to account for the change from day to night.

The implications of past research into children's cosmologies and explanations for the day/night cycle suggests that students may be developing their understanding of objects motion from their perspective in ways that are not consistent with actual observations of these celestial objects. From this we may conclude that we need to pay attention to the progression of how children *both* explain actual celestial motion *and* describe the apparent motion of celestial objects from their perspective. In this paper, we propose a learning progression for apparent celestial motion based on interviews with children across elementary and middle school, designed around the "big ideas" of apparent celestial motion. We then test this progression against an instructional intervention.

Because of the significant differences in the overall patterns of motion of the sun, moon and stars, and children's development of understanding these concepts, each will be described as a separate strand on the learning progression:

1. The sun's path is a smooth arc across the sky that slowly changes in length and altitude across the seasons.
2. The moon moves across the sky on a daily basis in a similar path to the sun, sometimes during the day and sometimes at night.
3. The pattern of stars remains the same but appear to move across the sky nightly. The stars visible after sunset change slowly across the seasons.
4. The appearance of the moon changes slowly in a cycle that lasts about a month.

Both the second and fourth big ideas relate to the moon. They have been separated here for two reasons. First, each has a different causal explanation (rotation of the earth versus relative position of the sun, moon and earth). Second, students initially are likely to develop these concepts separately.

Methodology

The development of this learning progression began with a domain analysis of the aspects of astronomy relating to the patterns of apparent celestial motion. By using the logic of the discipline, we identified the big ideas of apparent celestial motion that form the end-points of the proposed learning progression: what students should know from a scientific perspective. This domain analysis also allowed us to identify concepts that will be important for a full understanding of more advanced concepts in astronomy. Our decision to include specific concepts as big ideas was supported by their inclusion in the Benchmarks for Science Literacy (AAAS, 1993) and the National Science Education Standards (NRC, 1996).

A close examination of the literature was performed to identify those areas in which knowledge of these concepts has been investigated among various populations. The existing literature includes studies of children (Baxter, 1989) and adults' ideas (Mant & Summers, 1996) about the patterns of apparent celestial motion and studies that examined children (Baxter, 1989; Klein, 1982; Samarapungavan, Vosniadou, & Brewer, 1996; Vosniadou & Brewer, 1994) and adults' (Atwood & Atwood, 1995) explanations for the motions involved in the day/night cycle. These studies provided support for the creation of levels along the learning progression and informed the development of an interview protocol and instructional intervention on apparent celestial motion.

An initial learning progression was developed using the results of a previous study by one of the authors (Plummer, 2008a). This study examined elementary and middle school children's ideas about apparent celestial motion, as learned through traditional schooling, observations of the world, and cultural interactions. Analysis of the trends in students' ideas across the grades was used to describe how students move from naive ideas about apparent motion through descriptions of increasing sophistication. This progression we developed from these interviews places the concepts along *levels* of increasing accuracy, rather than grade ranges. We take the position that advancement along a learning progression is not a function of age or grade level; rather it is the result of experiences with the world and instructional practices. To assess students' ability to describe the patterns of celestial motion from their earth based perspective an interview protocol was developed based on the prior domain analysis of astronomy and examination of the literature. Students were individually interviewed under a small dome representing the sky (Figure 1). Students used a flashlight to represent the sun, moon and a star on the artificial sky and to describe their understanding of the motion. Twenty students each from first, third, and eighth grade (N=60) were interviewed.

Figure 1: Dome used in the interviews.

The next step after creating a learning progression is to test its usefulness in describing student improvement after an instructional intervention. An instructional intervention was created based on the conceptual levels identified in Plummer (2008a). A 45-minute planetarium program on apparent celestial motion was designed to build on children's prior knowledge of celestial motion and to engage students as active participants in the program. By assessing the range of student ideas in the first study, activities were designed that would directly address common alternative ideas about celestial motion held by early elementary children. The students participated in the planetarium program through the use of kinesthetic learning techniques (KLTs). KLTs describe two different ways children were using their own motion during the program. First, the children used their hands and arms to make predictions about what the apparent motion of the sun, moon and stars would look like in the sky, based on their prior knowledge or previous observations made in the planetarium. Second, the children were asked to point to and then follow the motion of objects as these were demonstrated throughout the program. The KLTs were designed to focus the children's attention on the key topics of apparent celestial motion. A sample of students from seven first and second grade classes were interviewed (N=63) before and after each class attended the planetarium program. This study has been reported in Plummer (2008b). We have used the results of this study to report how this method of instruction can move students along the learning progression proposed in this paper.

Learning Progression for Apparent Celestial Motion

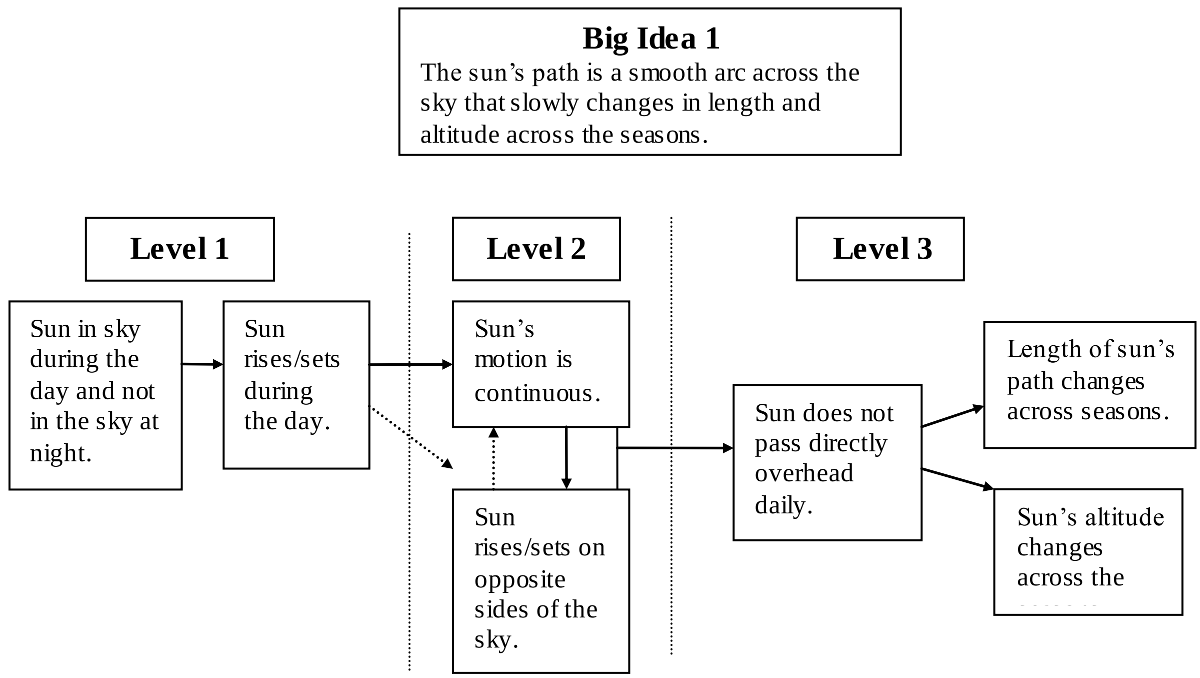
Big Idea 1: The sun's path is a smooth arc across the sky that slowly changes in length and altitude across the seasons

The progression described in this section describes both features of the sun's motion that occur because of the earth's rotation on its axis, but also because of the earth's orbit around the sun on a tilted axis. The appearance of this motion is also mediated by our location on the curved surface of the earth. In the case of the students interviewed for this study, their location at 40 north latitude causes the sun to appear to rise and set every day at an angle slanted towards the south, never passing through the zenith position. The path of the sun shifts further south as we move towards winter and then further north as we move towards summer. Figure 2 shows the suggested learning progression for the pattern of motion of the sun. Progressing through to understand the concepts in Level 3 is necessary to fully understand the reasons for the seasons.

Level 1: The learning progression begins with the level of understanding we may expect as children enter school. This provides an anchor from which to build successively more sophisticated concepts. The first basic element of the sun's apparent motion held by children is that the sun is in the sky during the day. Students then develop the concept that during the day the sun appears to rise up and then set. Whether or not a student believes that the sun appears to move in the sky during the day may influence how they explain the occurrence of day and night (Vosniadou & Brewer, 1994). Students who do not make these observations about the sun's apparent change in position during the day may also not believe that the sun is "down" at night. Instead, they may explain the sun's disappearance at night by saying that the sun is behind clouds, behind the moon, or has moved out into space (Baxter, 1989; Vosniadou & Brewer, 1994).

Eighty-percent of the first grade students and 95% of the third grade students understood that the sun appears low in the morning, high during mid-day, and low at the end of the day before setting (though what happened in between those times did not always match the actual path of the sun). This suggests that early elementary students are likely to easily acquire this level of knowledge though some first grade students may require focused instruction beyond what they may notice on their own. The *Benchmarks* recommend that in kindergarten through second grade children should learn about astronomy by making observations of the sky. Such observations could include the sun appearing low in the sky in the morning, high in the sky later in the day, and then low in the sky at the end of the day. Knowledge of these changes in the sun's position in the sky may then help students to form the next concept in the progression.

Figure 2: Learning progression for the apparent motion of the sun



Level 2: After developing the concept that the sun appears to rise and set, children learn one of two different aspects of the sun's apparent motion: the sun's motion appears continuous or the sun rises and sets on the opposite side of the sky. Acquiring each of these concepts requires a complex set of observations if a child is to learn this from his or her own observations. While a child may notice that the sun appears successively higher from morning until the middle of the day and then lower at the end of the day, the observations necessary to conclude that this motion took the sun across the sky (rather than just up and down on one side of the sky) require comparing the sun's position to fixed points along the horizon. Without instruction this may be beyond most early elementary children's abilities. Guidance by an expert could help students recognize this change in the sun's location by pointing out how the sun's position has changed with respect to familiar objects along the horizon.

Even though a quarter (25%) of third grade students described the sun as rising and setting in nearly the same position, all of the third grade students demonstrated that the sun does not stop moving throughout the day[1]. Based in the interview results, learning one concept (the sun moves continuously) does not seem to depend on learning

[1] However, one third grade student appeared to have difficulty demonstrating the motion of the sun, and two others indicated that the speed of the sun's motion changed.

the other (the sun moves from one side of the sky to the other). In first grade, the majority of the children did not demonstrate that the sun moves continuously across the sky though some knew that the sun rises and sets on opposite sides of the sky. The third grade students knew that the sun's motion does not remain unmoving at the top of the sky although a large fraction of children did not know that the sun does not rise and set on opposite sides of the sky. This may be due to a lack of experience in observing the location of where the sun rises and sets or because children are still developing their spatial orientation abilities (Roberts & Aman, 1993).

The concepts described in Levels 1 and 2 are those that the eighth grade students had already mastered. The concepts of Level 3, which go beyond this simple description of the path of the sun, are ones that none of the eighth grade students understood. The concepts explored in this portion of the learning progression are primarily the result of the curvature of our earth and the tilt of the earth with respect to its axis. This includes the concepts that the sun does not pass directly over one's head everyday (true everywhere on earth), and that the sun's path gets longer and higher as the observer's hemisphere moves from winter to summer. The seasonal change of the sun's path is important in learning to fully explain why we experience seasons. *Benchmarks* does not include the concept of the sun's changing path over the seasons, though it is included in the K-4 section of *NSES*.

The concept that 'the sun does not pass directly overhead' is the next logical step for students to learn after they understand that the sun's apparent motion can be described as a smooth arc across the sky because it makes modifications to that basic notion. Previous surveys of middle school (Trumpler, 2001a) and high school students (Lightman & Sadler, 1993; Trumpler, 2001b) found that the majority of students believe that the sun passes directly overhead everyday. This misconception may be perpetuated by the everyday saying that the sun is "over head." None of the first grade students and a few of the older students (20% in third and 10% in eighth grade) demonstrated that the sun does not pass directly overhead in summer and winter (these students live in northern latitudes where the sun never reaches an altitude higher than 73.5 degrees). However, only one of those students, an eight grade student, also accurately described the sun's path across the sky; the others demonstrated non-scientific paths.

The seasonal change in the sun's path length and altitude also appears to be a challenging concept for students to master with traditional instruction and experiences. First grade students can be characterized as primarily moving into level 1. Many third grade students had achieved a Level 2 description of the patterns of motion. Most eighth grade students are also found at Level 2. None in this study had reached a full Level 3 understanding: none demonstrated a change in the length of the sun's path across the seasons and only 15% indicated that the sun is lower in winter than summer.

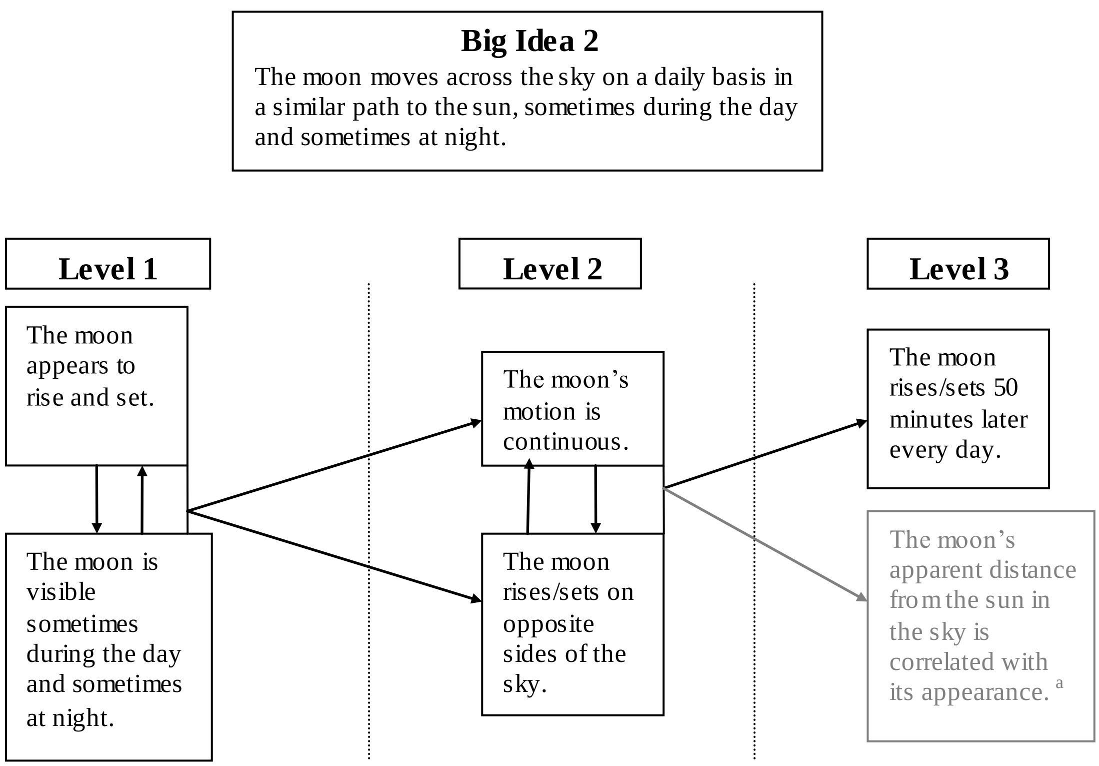
Big Idea 2: The moon moves across the sky on a daily basis in a similar path to the sun, sometimes during the day and sometimes at night

At first order, the moon's apparent motion is the same as the sun – rising and setting along the same tilted path that depends on your location on the earth – because the motion is a result of the rotation of the earth. The moon's slow orbit does cause the moon to rise approximately 50 minutes later every day and results in the slow changing of its appearance in the sky. Figure 3 shows the learning progression for students' understanding of the apparent motion of the moon.

At Level 1, students understand that the moon appears to rise and set and/or the student knows that the moon can be seen in the day or the night. The development of these ideas are not necessarily linked or dependent.

All first grade students believed that the moon does appear to move and the majority (90%) gave some indication of the rise and set concept for the moon through description or demonstration. About half of the first grade students (55%) indicated the same pattern of motion for the moon as they had previously indicated for the sun (primarily non-scientific paths). This may be connected to the common belief among young children that the moon and sun move opposite in the sky, with one rising as the other sets (Vosniadou & Brewer, 1994). The idea that the moon is visible sometimes during the day and sometimes at night provides a basis for learning that the moon rises and sets at different times at a later stage in the progression. The interviews with first grade students show that many (40%) still believe the moon can only be seen at night but by third grade most know the moon is visible during the day (80% of third grade students from this study).

Figure 3: Learning progression for the apparent motion of the moon



[a] This concept is part of Big Idea 4.

Just as with the apparent motion of the sun, at Level 2 of the learning progression students should develop understanding of a) the moon's *continuous* apparent motion and b) the moon rises and sets on the opposite sides of the sky. These concepts are not logically linked and the interviews with third grade students suggest that children are capable of understanding one without understanding the other. From a conceptual stand point, the idea that the moon's motion is continuous and from one side of the sky to other extends the earlier concept that the moon rises and sets. It also connects to the apparent motion of the sun because of the similarity in paths.

A shift towards Level 2 occurred by third grade for the students in this study. The majority of third grade students (85%) believed that the moon moves continuously through the sky where as the majority of the first grade students (60%) believed that it remains at the top of the sky for an extended period of time. The majority of third grade students (70%) also demonstrated that they believe the moon rises and sets on opposite sides of the sky. However, fewer eighth grade students could be place at Level 2 or higher. While nearly the same number (90%) gave a description of continuous motion, a many (35%) of the students believed that the moon remains in the sky during the day and night rather than rising and setting on opposite sides of the sky (only 10% of third grade students held this notion). We propose three possibilities for the genesis of this shift towards less accurate descriptions of apparent motion as the result of inaccurate interpretations of instruction on the actual motion of the earth and moon. First, students who learn that the moon is visible in both the day and night may conclude the moon is visible every daytime and every nighttime. This may lead them to conclude that the moon stays up in the sky all of the time. Second, when students learn that the moon orbits around the earth, they may interpret this to mean that the moon appears to circle around in our sky. Third, some students (in particular the students who say that the moon never appears to move) may have interpreted the concept 'the moon stays in place but the earth rotates' to mean that the moon does not *appear* to move as well. Each of these possibilities suggests the need for care when teaching students about actual celestial motion to also include the consequences to apparent celestial motion.

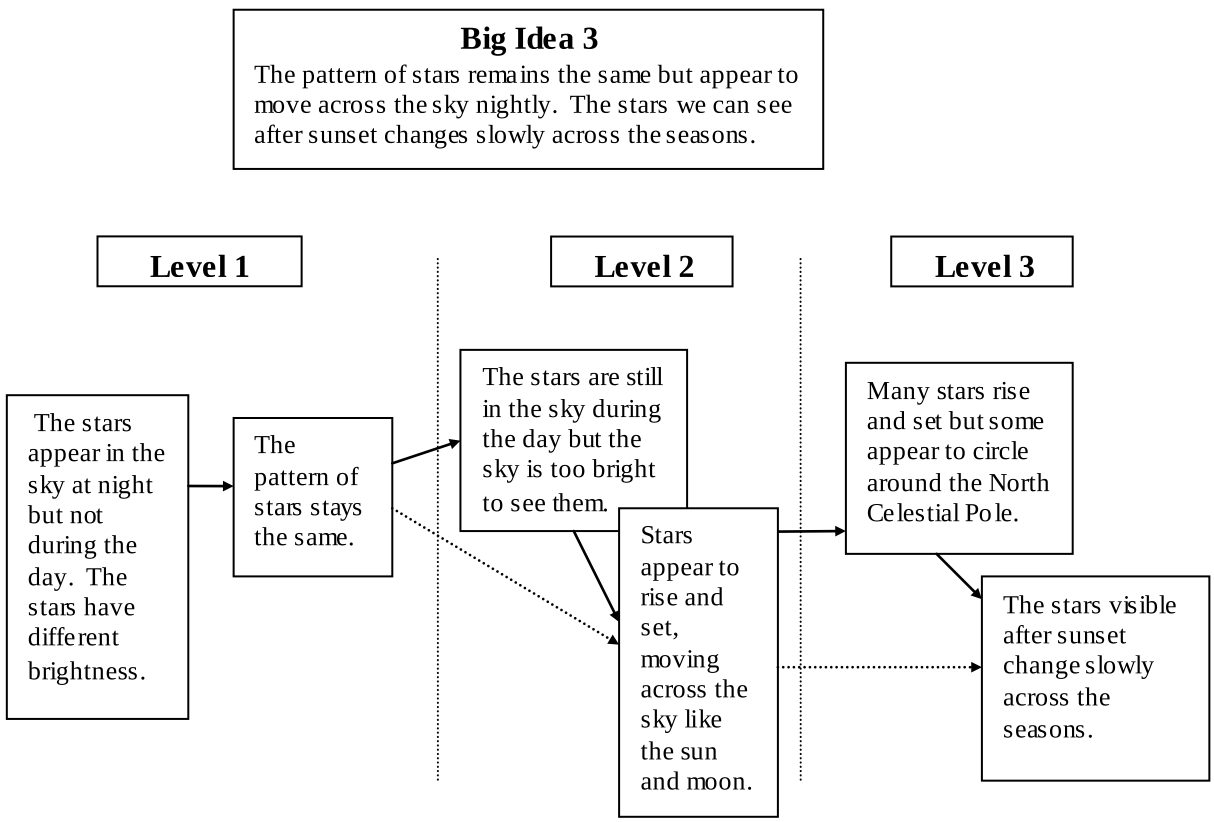
Two aspects of the moon's apparent pattern of motion are placed at Level 3: 1) the moon rises about 50 minutes later every day and 2) the moon's appearance changes as it is closer and further from the sun in the sky. These concepts are not explicitly mentioned in either the *NSES* or the *Benchmarks*. However, both of these concepts are a necessary part of a full understanding both the moon's apparent motion and the phases of the moon. The second concept is also placed in the learning progression for Big Idea 4 and will be discussed later in this paper. Neither concept was assessed in Plummer (2008a) because these go beyond the basic levels of understanding for early elementary, which was the focus of that study.

Big Idea 3: The pattern of stars remains the same but appear to move across the sky nightly. The stars visible after sunset changes slowly across the seasons.

The third aspect of apparent celestial motion describes the motion of the stars during the night and how the pattern of stars we see changes across the seasons. The learning progression for this topic is shown in Figure 4. To understand that the stars continually to rise and set throughout the night requires the learner to believe that the earth is surrounded by stars in all directions so new stars will appear over the eastern horizon as old stars disappear as they set in the west. The actual reason this motion occurs is because the earth is surrounded by stars in every direction. The stars are at such a great distance that they do not appear to be moving with respect to each other, forming fixed patterns in the sky that we call constellations. As the earth rotates, the stars appear to rise and set throughout the night; this pattern continues throughout the daytime but we are unable to observe this because the scattering of sunlight in the atmosphere.

The concepts at Level 1 were not directly assessed in Plummer (2008a): the stars appear at night but not the day and the stars remain in the patterns of stars stay the same. The pattern of stars in the sky does not change with respect to each other. Understanding this concept could include beginning to learn about the constellations and will be a useful concept to establish before attempting to address the full extent of the pattern of apparent stellar motion. Further study is needed to understand the progression of children's ideas in this area.

Figure 4: Learning progression for the apparent motion of the stars



Without well-designed instruction many children will not have an accurate understanding of the concepts at Level 2 of the learning progression by the end of elementary school: the stars are still in the sky during the day and the stars appear to move slowly across the sky, like the sun and the moon. Only half (45%) of the third grade students understood that the stars are still in the sky during the day, but not visible because the sky is too bright. Vosniadou and Brewer's study (1994) also found that only 45% of third grade students and 60% of fifth grade students knew there were stars in the sky during the day. The concept shows improvement with older students: 85% of the eighth grade students were aware of the stars' daytime location.

At Level 2, students understand that the stars' location appears to change slowly, rising and setting like the sun, but not a full description of the stars' pattern of motion (which would include understanding the circumpolar motion of stars near the celestial poles). Studies of elementary and middle school-aged children as well as adults suggest that students are not learning this pattern of motion and that many are not aware that the stars appear to move at all (Mant & Summers, 1993; Plummer, 2008a; Plummer, Rice & Zahm, 2008; Sharp, 1996). Only half of the third grade students believed that the stars appear to move and another 20% believe the stars only move at the end of the night; there was no difference in the number of students in eighth grade who believe the stars appear to move compared to the third grade, though slightly more were able to describe this motion (Plummer, 2008a). Even less (14%) of the 10- and 11-year old students in Sharp's (1996) study believed that the stars appear to move (though the difference in interview techniques may explain this difference in the percentages). Among the elementary school teachers interviewed by Mant and Summers (1993), all were aware of the apparent motion of the stars but only 20% were able to describe that motion.

Some students may find the apparent motion of the stars contradictory with the idea that stars are still in the sky during the day. Vosniadou and Brewer (1994) suggest, based on their interviews with elementary students, that students who think the stars do not move believe that they are still in the sky during the day and vice versa. This may also be why some of the first (30%), third (10%) and eighth grade students (10%) suggested that the stars only move at the end of the night. If they believe there are no stars in the sky during the day (supported by their observations of the daytime sky) then they must explain that change by moving the stars out of the sky at the end of the night.

Only 15% of the eighth grade students were aware that the stars we see after sunset are not the same as the stars we see before sunrise because of the rising and setting motion. The majority (80%) believed that we see the same stars all night long. This suggests that instruction needs to emphasize that we see different stars throughout the night because of the rising and setting motion of the stars.

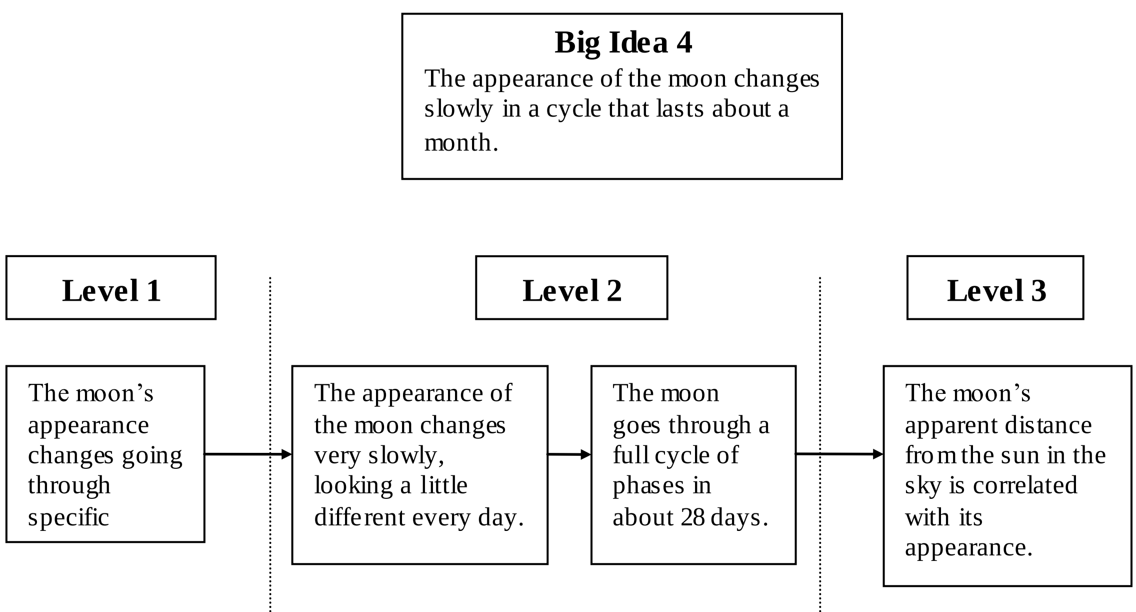
Level 3 of the stars' apparent motion include a) the full description of the stars' apparent motion throughout the night and b) the change in the stars we see over the seasons. The first concept builds on the goals of previous stages of the learning progression but it also relates to the students' understanding of the patterns of motion of the sun and moon. Once students have mastered the rising and setting patterns of the sun and moon, they may find it easier to describe the stars as exhibiting a similar pattern of motion. But developing this knowledge will require instruction that helps the students imagine the nature of this pattern of motion. The interviews with the eighth grade students, as well as studies of elementary in-service (Mant & Summers, 1993) and pre-service teachers (Plummer, Rice & Zahm, 2008) demonstrate that learners, through adulthood, are likely to be unable to describe the stars' apparent motion without instruction.

The final piece aspect of the apparent motion of the stars is the concept that we see different stars after sunset during different seasons. By middle school, the *NSES* and *Benchmarks* recommend that students learn about the earth's orbit around the sun. However, at present, there exists no relevant research to report on children relating our observations of different stars across the seasons to other aspects of the stars' learning progression. This area will require future work to adequately place it along a learning progression in relation to both apparent and actual celestial motion.

Big Idea 4: The appearance of the moon changes slowly in a cycle that lasts about a month

The shape of the moon appears to change slowly over the course of 28 days before beginning the cycle again. As the moon orbits the earth we see first more of the side facing the sun and then less of the illuminated side. However, children in elementary school are likely to have difficulty understanding and using the explanation for the apparent change to the moon's appearance (Baxter, 1989; Kavanagh, Agan, & Sneider, 2005; Stahly, Krockover, & Shepardson, 1999). The purpose of this strand of the learning progression is to suggest how children may build upon early observations to a complete understanding of the observational aspects of this change. If children have this full descriptive understanding of the phases of the moon they may be more successful in learning the explanations for the pattern of change. Figure 5 shows the suggested learning progression for the moon's appearance.

Figure 5: Learning progression for the change in the appearance of the moon



The majority of first grade students (75%), all third grade students, and most of the eighth grade students (90%) could be place at Level 1 by making at least two drawings of the shape of the moon and indicated that they were aware of the change in the moon's appearance. The steps at Level 2 build one upon the other: the moon's appearance changes very slowly and the moon goes through an entire cycle of phases in 28 days. Half of the third grade students (50%) and 70% of eighth grade students had reached at least the first concept of Level 2, giving an accurate answer to the length of time it would take to observe a significant change to the moon's appearance. Most of the students with alternative ideas believed that this change could occur in minutes or hours.

The question of exactly how long the phases of the moon occur was not asked in this study.

There is a lack of research the conceptual area at Level 3: when and how learners correlate the moon's apparent distance from the sun in the sky to its appearance. A large portion of middle school students do not have an accurate understanding of the moon's path across the sky or the time it takes for the phases of the moon to change. This suggests very few students will notice this pattern on their own. It is also likely to go beyond what most instruction focuses on currently.

Instructional Intervention: Movement along the Learning Progression

Learning progressions are not created solely on analysis of the discipline and conceptual interviews. They need to be tested by analyzing changes in student understanding after instructional interventions. In this section we will explore how a planetarium program helped move first and second grade students along the proposed learning progression. The instructional intervention examined in this section primarily focused on concepts found in Levels 1 and 2 of the learning progression for two reasons. First, the planetarium program was only 45 minutes in length, limiting the amount of material that could be included in the instruction. Second, most children attending had not reached Level 1 for many of these big ideas. This led us to focus on developing their understanding towards the first two rungs of the progression.

For the remainder of this paper the investigation of first, third, and eighth grade students' ideas (Plummer, 2008a) will be referred to as Study A; the study of first and second grade students who attended a planetarium program (Plummer, 2008b) will be referred to as Study B.

Instruction Addressing Big Idea 1: The Motion of the Sun

Prior to the planetarium program, the first and second grade students were similar to the first grade students of Study A. The majority of students could be characterized as Level 1 (32%) or Level 2 (65%). With planetarium instruction, 86% of the first and second grade students had reached Level 2, a significant improvement from before instruction. The first and second grade students in Study B showed significant improvement in understanding that the sun does not pass directly overhead in the Midwestern United States, a concept placed in Level 3. Without instruction, none of the first or second grade indicated that the sun does not pass through the zenith during the summer; after the planetarium program 57% accurately demonstrated that the sun does not pass through the zenith. Level 3 also included understanding of the shift in the sun's path across the seasons. Prior to instruction, some students expressed knowledge of the change in the sun's path length (6%) or change in altitude (21%) across the seasons. However, most of these students had other errors in their overall description of the sun's path and thus had not reached Level 3 of understanding. After instruction, 60% of students could accurately compare the length of the sun's path across summer and winter, and 63% students gave an accurate description of the change in the sun's altitude. Thus this planetarium program helped over half of the students' progress to a Level 3 description of the motion of the sun, a more advanced description than given by middle school students in Study A.

Previous studies of children and adults' knowledge of the seasons, both with and without instruction, have primarily focused on how they explain this difference in terms of the tilt of the earth without also testing how subjects explain what we can observe or experience (Atwood & Atwood, 1996; Parker & Haywood, 1998; Sadler, 1992; Trumper, 2001a; 2001b, 2001c). Study B shows that children as young as first and second grade can begin to learn that the sun's path changes across the seasons, though not all students showed improvement (possibly because they had not already learned the prior concepts of the learning progression or they were hindered by conflicting non-scientific mental models). In addition to the planetarium, this concept is accessible to students through direct observations (though these observations must be made over a long period of time and are likely to need a high level of guidance from more expert observers). Because this concept addresses a phenomenon that is observable, these aspects of the seasons may be more appropriate for children to learn first, and at a younger age, than the more abstract aspects of the seasons that combine understanding the earth's rotation, tilt and orbit. Planetarium instruction improves children's ability to describe these changes, but waiting until upper elementary school to study these changes may provide a better foundation for when they learn to explain the seasons.

Salierno, Edelson, and Sherin (2005) conducted a case study with three fifth-grade students of how the knowledge of the seasons changed after participating in an in-depth investigation about the earth's surface temperature. The instruction, which focused on the angle of the sun's light and the tilt of the earth, helped the students achieve a partial understanding of the seasons but they retained some of their initial alternative ideas. Traditionally, the seasons are taught by introducing the tilt of the earth without helping them understand all of the consequences. An open question remains as to whether teaching children to notice changes to the sun's path and altitude across the seasons may help them form a more complete and accurate understanding when exposed to instruction on the tilt-explanation of the seasons.

Instruction Addressing Big Idea 2: The motion of the moon

Prior to the planetarium instruction, 17% of the first and second grade students did not describe the moon's motion as a rising and setting, though most did show the moon moving in the sky, often in an up and down motion, but always staying in the sky and 14% of students did not believe that the moon can be seen during the daytime. Two-thirds (66%) of students could be placed at Level 2 for the motion of the moon. After planetarium instruction, the number of students who demonstrated Level 2 understanding increased to 81% of students accurately describing the moon as appearing in the day and night, demonstrating that the moon rises and sets across the sky and understanding the continuous nature of the moon's motion. Instruction designed to explicitly demonstrate the smooth, continuous nature of the moon's motion appears to help students improve to a scientific description.

This study did not explicitly focus on teaching concepts relating to Level 3 (shift in the rise and set time) and therefore the children's understanding in this area was not assessed. Vosniadou and Brewer's study of first, third, and fifth grade students found that children often believe that the moon rises as the sun sets, and vice versa, despite knowing that we can see the moon in the sky during the day at times (1994). For some, this corresponds to children's mental model that the sun and moon are fixed on opposite sides of the earth and appear to rise and set as the earth turns. For other children, the sun and moon move up and down in opposite motions, like a hydraulic system. Many children believe that the moon is causal in the occurrence of night. It may be necessary to address children's full explanatory model to teach the concept that the moon rises and sets 50 minutes later every day.

Instruction Addressing Big Idea 3: The motion of the stars

Prior to the planetarium instruction, students were assessed on their knowledge of the location of the stars during the day and night, and their apparent motion, but not concepts relating to Level 1: constellations (stars maintaining set patterns in the sky) and differing brightnesses. Most students (89%) were at Level 1 or lower, based on their lack of understanding of the rising and setting motion of the stars. Slightly more than half of the students could give an accurate response to the Level 2 concept, location of the stars during the daytime. Planetarium instruction helped move these students along the progression to Level 2, bringing almost half to this level of understanding: 62% could describe the motion of stars and 43% knew that this motion meant that we see different stars throughout the night. Further, 79% knew that the stars were still in the sky during the daytime when we cannot see them.

The rising and setting motion of the stars would seem to be an area that the planetarium is particularly well suited. The fact that many children did not successfully reach Level 2 from this planetarium instruction may indicate the difficulty of this concept as well as the short length of the intervention. If students had previously studied the patterns of stars or the idea that the stars surround the earth, perhaps more students may have been successful. Instruction that improves students' understanding of the apparent motion of the stars but does not include the planetarium (or planetarium-like software on a computer) will be challenging to implement. Making observations that the stars appear to move requires first, that the student go out and make multiple observations over an hour or so at night and second, that the student has the ability to recognize a single star in order to track its position. Without the aid of a planetarium to demonstrate these motions on a faster time scale, instruction on the apparent motion of stars may require that students understand the reason why the stars appear to move: the rotation of the earth. This is certainly an area that will require future research to establish the most successful course of instruction on these topics.

Teaching this concept from the perspective of the earth's rotation in a classroom may not be successful for many students if it is not explicitly taught. In a study of instruction that focuses on the earth's rotation but did not specifically apply this to the appearance of the stars in the sky, Diakidoy and Kendeou (2001) found that 31% of fifth grade students did not infer that the stars are still in the sky during the day. Their study did not explicitly assess the apparent motion of the stars, but without knowing that the stars are still in the sky during the day students are going to be limited in their ability to fully describe the stars' rising and setting motion. This suggests that instruction needs to account for children's mental models of the stars' location around the earth and address how the rotation of the earth relates to our observations of the stars (which were not part of Diakidoy and Kendeou's instruction).

Because the students targeted in this instruction were starting at Level 1 or below, Study B was not designed to address or assess concepts in Level 3. Based on the results of the study this seems reasonable given that most children were still acquiring a Level 2 understanding.

Instruction Addressing Big Idea 4: Changing appearance of the moon

Research on children and adults understanding of the phases of the moon demonstrates how challenging it is to gain a scientific understanding of this phenomenon even with extended instruction (Barnett & Morran, 2002; Baxter, 1989; Kavanagh, Agan, & Sneider, 2005; Stahly, Krockover, & Shepardson, 1999; Trundle, Atwood, & Christopher, 2002, 2007). Here, we focus on how children learn to describe the changes in appearance without tying this to the explanation for the phenomenon. Almost all children in these studies knew the Level 1 concept that the moon's appearance changes and could draw at least two different phases, but prior to instruction, most children had not reached Level 2 in their understanding of the timescale in which this change occurs. Over half (63%) indicated inaccurate ideas about how long it takes for the moon to change phases (most believing that the moon's appearance changes significantly over the course of a single night). Planetarium instruction helped move students along the learning progression; after instruction 66% accurately stated that it takes longer than a single night for the moon's appearance to change significantly. However, this instruction did not specifically teach children that the pattern of phases occurs every 28 days so this aspect of the learning progression was not assessed.

Trundle, Atwood and Christopher (2007) examined 48 fourth-grade children learning to describe and explain the changing phases of the moon. Their study used a much stricter interpretation of children's drawings of the various phases of the moon than Plummer (2008a, 2008b) in order to examine how children's knowledge of the full cycle of phases of the moon improved through a 9-week observation period of the lunar phases. Prior to instruction, the majority of children knew that the moon has phases (though they did not have a fully articulated description of this changing appearance) and 81% of the students knew that the moon's changing appearance is in a predictable pattern). Instruction that included observations of the moon allowed 77% of the students to attempt to draw all of the major phases of the moon after instruction and the majority accurately represented both the waning and waxing sequences. All of the students stated that the moon moves through a predictable pattern of appearance after instruction. While the Trundle, Atwood and Christopher study did not ask students about how long it takes for the change in appearance of the moon (and thus we cannot directly place these students on our learning progression) this work is promising for showing how students may improve their understanding of the apparent changing shape of the moon.

Summary and Conclusions

This paper presents a learning progression for how children may move from novices to experts in their understanding of the patterns of apparent motion. This progression takes into consideration the ideas expressed by students in elementary and middle school as the result of traditional instruction and observations of the world. These experiences are not sufficient to help students move beyond an intermediate level of understanding, even by adulthood, in this concept area; targeted instruction is necessary. Planetarium instruction which utilizes kinesthetic learning techniques was successful in improving even early elementary students descriptions of apparent celestial motion, even to levels beyond what the majority of middle school students had achieved. The development of this learning progression places new emphasis on the importance of students learning these patterns of celestial motion in a way that is different from current practice in school. Recognizing that students may need to develop increasingly sophisticated ways of describing the sun, moon and stars from their perspective may help improve their ability to explain these phenomena beyond just focusing on instruction that primarily addresses the actual rotation and revolution of the Earth. The planetarium instruction examined here used an approach that gave the students an opportunity to visualize these motions from their own perspective in a way that is not readily available in most classrooms given both resources and that many teachers do not fully understand these motions themselves.

A major limitation of the research presented here was the short duration of the planetarium intervention: a single 45-minute planetarium program. The brief nature of this instructional piece limits our understanding of how sustained engagement in the topic may move students along this progression. Additional research is needed that extends instructional time to include both the planetarium and classroom instruction, or observations of the actual sky. This learning progression should be tested through research on a variety of instructional strategies, with many populations of students across age levels and backgrounds. Fortunately, recent trends in astronomy education research show a movement towards studies that test instructional strategies (Kavanagh, 2007). Instruction in the planetarium has been shown to successfully move early elementary students through more sophisticated levels of understanding of celestial motion. Most students do not have easy access to the planetarium environment as part of their education so alternative instructional interventions should be tested against this new progression. Instruction that takes place in the classroom may offer new insights into how students progress in this area and demonstrate alternative successful paths of learning. Such opportunities could give students a more extended amount of time focused on these concepts and alternative ways of exploring patterns of celestial motion. Another area of research on children learning about celestial motion that is missing is the use of students own observations of celestial objects as part of instruction. The impact, as well as the challenges, of incorporating such study into classroom instruction should be explored as part of assessing this learning progression. Longitudinal studies are also need on these concepts to examine how stable the changes in understanding may be. This will become more important as students are learning about subsequent topics in astronomy that will build on a foundation of observational knowledge. These studies may also be able to test the progression for movement from Level 2 to Level 3, concepts that in general were more sophisticated than was attended to in the planetarium program describe here.

One of the major areas in need of research on instruction and assessment is the connection between learning the patterns of celestial motion and explaining those motions with the *actual* motion of the earth and moon. To what level should students learn the patterns of apparent celestial motion, such as the sun's pattern of rising and setting, before learning to explain with the earth's rotation? Does a good foundation in the patterns of apparent motion help students to later learn the explanations? Or, if we first have students focus on learning the actual rotation of the earth, will they easily make the leap to both describing and explaining apparent motions? The full answer may be an iterative approach that connects observational astronomy to modeling across the grade levels.

Finally, research on the prior knowledge of elementary teachers (and pre-service elementary teachers) has shown these educators to hold the same alternative ideas about apparent and actual motion as elementary students (Abell, Martini, & George, 2001; Atwood & Atwood, 1995; Atwood & Atwood, 1996; Mant & Summers, 1993; Plummer, Rice, & Zahm, 2008; Trundle, Atwood, & Christopher, 2002). How do we design educative curricula that meet the needs of these teachers, to help them reach the full scientific understanding of these concepts, preparing them to help guide their students through such a progression of concepts? Without addressing this problem, we will not be able to advance student learning.

The work described here advances the literature by presenting one of the first learning progressions, developed from students' ideas across various ages and then tested against an instructional intervention. This type of research is needed by the science education community to demonstrate the usefulness of the approach advocated in *Taking Science to School* (Duschl, Schweingruber, & Shouse, 2007). Our development of a learning progression for apparent celestial motion also advances the field of astronomy education presenting a new way of looking at moving the field forward. Astronomy education research has an extensive history of uncovering misconceptions and to a more limited extent on examining how specific instructional interventions may improve students' understanding. The development of learning progressions in astronomy will allow us to approach the assessment of new interventions with an eye towards moving students along a pathway towards scientific understanding, rather than from a perspective of success or failure. From this, we may better be able to suggest how limited classroom time can be used effectively to help students learn astronomy. The learning progression for apparent celestial motion provides a structure for creating and testing instruction that supports elementary students' development towards scientific understanding.

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