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A LEARNING PROGRESSION APPROACH TO TEACHER PROFESSIONAL DEVELOPMENT IN ASTRONOMY

Extensive research has shown that students' understanding of astronomy does not resemble the scientific view. This study builds on our previous research in the area of celestial motion to examine how children develop an understanding of the connection between the apparent motions of the sun, moon and the stars in the sky and the explanation for these motions, using the earth's rotation and the moon's revolution. Based on analysis of the domain, close examination of existing research, and the range of ideas expressed by third grade students before and after classroom instruction, a learning progression was developed. We have collected interview data from third grade students from two instructional inventions: gifted third grade students participating in a short targeted intervention (N=16) and four regular third grade classrooms participating in their normal 6-week astronomy curriculum (N=24). In this paper we will examine the use of the progression in analyzing the outcomes of the instruction and providing insights for how future instruction may be improved to address students' alternative conceptions. We will describe how the learning progression can be used to provide the framework for teacher professional development on celestial motion.

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Introduction

The basis for understanding many aspects of astronomy is the ability to use the actual motions and relative positions of celestial objects (e.g. the sun and moon) to describe observed phenomenon and make predictions about the future. The National Science Education Standards (NSES) recommend that students learn that "objects in the solar system are in regular and predictable motion" in 5th through 8th grades (NRC, 1996). Prior to this, the NSES recommends that students learn the observable patterns of motion of the sun, moon and stars. The Benchmarks for Science Literacy (AAAS, 1993) recommend that between 3rd and 5th grades students learn that the "rotation of the earth on its axis every 24 hours process the night-and-day cycle. To people on earth, this turning of the planet makes it seem as though the sun, moon, planets and stars are orbiting the earth once a day." An understanding of celestial motion is necessary for other standard topics of astronomy such as the phases of the moon and the seasons. And beyond this, a central way that astronomers (and scientists in general) make sense of the world is by looking for explanatory models to explain their human-centric observations. In this paper we focus on one aspect of this by targeting how children learn to shift from their own perspectives to a "looking down on the sun-earth-moon system" perspective while also linking these two frames of reference.

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Without targeted instruction, most children and adults will not reach a scientific level of accuracy in their descriptions of the apparent motion of the sun, moon and stars from an earth-based perspective (e.g. Baxter, 1989; Mant & Summers, 1993; Plummer, in press; Plummer, Zahm, & Rice, 2009; Sharp, 1996). Vosniadou and Brewer's (1994) study of elementary children's mental models of the day/night cycle suggests that students may begin with naïve but logically consistent and empirically accurate models and that their descriptions and explanations may become less consistent as they attempt to assimilate scientific concepts into their prior framework. Prior research has established that first and second grade students are capable of improving their descriptions of the apparent motion of the sun and moon through instruction in the planetarium to a level more advanced than most middle school students (Plummer, 2009). Other studies have shown that upper elementary children can learn the scientific descriptions of the shape of the earth and the day-night cycle through the use of models (Diakodoy & Kendeou, 2001). Recent studies have also shown that children can learn how to explain the phases of the moon through inquiry and modeling as young as 2nd – 4th grade (Hobson, Trundle, & Sackes, 2009; Trundle, Atwood, & Christopher, 2007). Currently, few studies directly examine the connections between how children describe apparent celestial motion and the explanations for this motion or the impact of instructional interventions on the full celestial system included in celestial motion (earth, sun, moon and stars).

In this paper, we will begin by reviewing the relevant literature which situates this work in past studies of children's understanding of the shape of the earth, the earth's rotation, and the moon's orbit. We will then explain the theoretical perspective we take, focusing on the creation of learning progressions and the prior research supporting our instructional intervention. Our goal is to demonstrate how an analysis of the discipline (celestial motion) combined with knowledge of children's ideas and development through targeted instruction can be used to develop a learning progression. This will then form the central guide about which professional development for third grade teachers will be developed. This manuscript will conclude with a description the proposed professional development and how it utilizes our learning progression work.

Children's Ideas Relating to Celestial Motion

Shape of the Earth

The greatest effort in research related to astronomy education appears in the area of children's initial understanding of the shape of the earth and gravity. Children's initial ideas have been assessed across age groups and across cultures. Children's initial understanding of the world is based on their personal interactions and observations leading to a general understanding that the earth is flat and unsupported objects fall down (Vosniadou & Brewer, 1992). As children are exposed to scientific concepts through cultural and school interactions, they find ways to incorporate the scientific concepts into their naïve framework (Nussbaum & Novak, 1976; Nussbaum & Sharoni-Dagan, 1983;

Vosniadou & Brewer, 1992). For most children the result is a synthetic model of the world that combines features of their observations and the scientific description of the world. Interviews with students across elementary grade levels have lead to a general categorization earth shape and gravity notions that supports the conclusion that there is a developmental progression from naïve to synthetic or scientific understandings, though not all students will reach that scientific understanding (Nusbaum & Novak, 1976; Nussbaum & Sharoni-Dagan 1983; Samarapungavan, Vosniadou, & Brewer, 1996; Vosniadou & Brewer, 1992).

Students also hold a range of gravity concept notions, with respect to their understanding of the earth. These range from the scientific description to initial ideas based on their experiences (Sneider & Pulos, 1983): gravity pulls objects to the center of the earth, gravity pulls objects on the surface of the earth towards the center (but outside of the earth there is a universal down), and gravity pulls "down" everywhere (thus people would fall off of the "bottom" of the earth). Students begin school with the initial naïve notion or possibly one of the ego-centric synthetic notions. But even by middle school, many students will not have attained the full scientific understanding of both earth shape and gravity (Nussbaum, 1979; Sneider & Pulos, 1983).

Rotation of the earth

A major pre-requisite towards understanding the earth's rotation is appreciating that the earth is an unsupported sphere. If children do not hold at least the notion that the earth is a spherical, unsupported body, they are likely to find it difficult to construct the scientific mental model of a rotating planet to describe the apparent motion of the sun, moon and stars. However, further studies are needed to determine the actual interaction children's knowledge of the shape of the earth and the rotation concept through studies that investigate instruction at early grades.

Research on children's explanations for the day-night cycle may shed light on how children develop the concept of the earth's rotation, as well as how their alternative conceptions will present, as they learn to explain apparent celestial motions. As with the earth shape and gravity notions, children's early explanations for the day-night cycle are primarily naïve and are based on observations of the world. Most young children begin schooling with the 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; Spelke, 1991; 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, in press; Samarapungavan, Vosniadou, & Brewer, 1996; Vosniadou & Brewer, 1994). In addition to these ideas, 6 of the 12 Mexican-American children in Klein's study (1982) gave responses that indicated the sun is not an inanimate object. Klein reports that the students described the sun as "hiding behind the mountains," "hiding behind the clouds" or "hiding behind trees" at night, which the author suggested was evidence of precausal thinking (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).

The second order constraints on children's understanding of celestial motion arise from how children understand the physical properties of celestial objects (Samarapungavan, Vosniadou, & Brewer, 1996; Vosniadou & Brewer 1994). Studies using interviewing techniques that include having children draw their ideas (American children; Vosniadou & Brewer, 1994) and use physical models (Indian children; Samarapungavan et al., 1996) have found a developmental progression of children's ideas, with older students moving towards more heliocentric explanations for the day-night cycle. Some of this development appears to be linked to the development of the spherical earth model. Vosniadou & 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 et al. (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.

In recent years, studies of children learning the concept of the earth's rotation have covered ages 9 through 12, though little research has been done with children at younger grades. Diakidoy and Kendeou (2001) compared two types of instruction on the day/night cycle and shape of the earth with fifth grade students (average age 10 years 5 months) in Cyprus. One type of instruction followed a standard, textbook-based curriculum. The second was designed to consider students prior knowledge and used interactive models to help students focus on explanations for the scientific phenomena. Students in the condition that was designed to facilitate conceptual change by considering their possible misconceptions showed significant improvement in understanding, at both an immediate post-test and a delayed post-test, over the students receiving text-based instruction. However, the results do not detail the nature of the change in understanding – it is not clear if students in one, both, or neither improved specifically on the earth rotation concept (specifically tested on two out of 14 multiple choice questions).

In a study of Year 5 and 6 children in England (ages 9-11), Sharp and Kuerbis (2005) used a quasi-experimental design to investigate the use of an astronomy intervention on the topic of the solar system, including a lesson on the day/night cycle. This lesson allowed the students to observe the rising and setting positions of the sun, follow the shadow of the sun throughout a day, and use a globe and overhead projector to explain why the sun appears to move. As with Dikodoy and Kendeou's study (2001), instruction involved physical models and considered children's prior experiences. Students showed significant improvement in their scientific conceptualization after instruction, improving from 35.5% in the pre-test to 77.4% in the post-test and 74.2% in the delayed post-test. A third study of twenty-seven 12 and 13-year –old Greek children learning about celestial motion found that all students understood the scientific model of the day-night cycle of rotation after experiencing a virtual computer environment where students could manipulate three-dimensional representations of the actual celestial objects to learn the concepts (however, the study did not include a pre-assessment on their understanding) (Bakas & Mikropoulos, 2003).

Teaching the concept that the earth rotates is not enough to allow students to make the full connection between the earth's rotation and the apparent daily motion of the sun, moon and stars. In a study of English Year 7 and 8 students, after spending 11 1-hour lessons focused on mental model building in astronomy (covering concepts of motion in the solar system and explanations of the phases of the moon and seasons), few (38%, up from 22%) understood that the "moon is in the day-time sky as often as it is in the night-time sky" though they made great improvements in understanding the full description of the moon orbiting the earth which orbits the sun (increasing from 48% to 90%) (Taylor, Barker, & Jones, 2003, p. 1120). Learning to correctly transfer their understanding of the earth's rotation to the apparent motion of stars also appear to be difficult for students. Diakidoy and Kendeou (2001) found that despite learning to explain the day/night cycle, 31% of the fifth grade students did not transfer this concept to infer that the stars remain in the sky during the day. Dove (2002) analyzed 12-year-old English students' responses to a question that asked them to explain why the bright star Regulus appears to move across the sky. Most students (78%) correctly indicated that the apparent movement is because of the earth's rotation and most also stated (73%) that the motion is east to west. However, the remaining portion of students could not accurately describe how and why this motion occurs (and it would be interesting to test these students without presuming they know that the stars appear to move across the sky).

The orbit of the moon

The rotation of the earth allows us to begin to explain the apparent rising and setting of the moon in the sky. Understanding the earth's rotation in conjunction with the moon's 28-day orbit around the earth is necessary for explaining the phases of the moon: a pattern of changing appearance of the moon over that same 28 day cycle. Research on children's ideas about the moon reveals both misconceptions about the moon's actual movement and that this motion is not used to explain patterns of apparent motion by children. In a study of American students, Vosniadou and Brewer (1994) found that some believe that the moon and sun are fixed on opposite sides of the earth, with the earth spinning between them for day and night (5 of 20 third grade students and 5 of 20 fifth grade students). Other students believed that the moon goes around the earth (4 students in third grade and 2 students in fifth grade) but the reason for this movement is to make night. Sharp (1996) found similar notions about 10- and 11-year old English children by examining the mental models they hold about the actual motion of the sun, moon and earth. Seventeen of forty-two students knew that the moon orbits the earth slowly and another one student believed that the moon orbits once per 24 hours. The remaining 22 students either believed that the moon is fixed in place (16) or were categorized as unsure (6). Of the 102 Greek 11-13 year olds in Bakas & Mikropoulos's study (2003), 76% knew that the moon orbits the earth. The remaining students either believed that the moon is stationary, moves in and out, orbits the sun along with the earth, or were unsure. And among the students who may be aware of the actual motion of the orbiting moon, many if not most do not know how to use this motion to explain the apparent changes to the moon's appearance or patterns of motion. Several studies have shown that children through adults cannot explain why we have phases of the moon (Abell, Martini, & George, 2001; Barnett & Moran, 2002; Baxter, 1989; Sharp, 1996; Stahly, Krockover, & Shepardson, 1999; Trundle, Atwood & Christopher, 2002). And while the explanations for the daily change in the moon's rise and set time has not been explored among students, it is reasonable to assume based on other studies that show children have limited knowledge of the basic patterns of celestial motion that children are even less scientific in their use of the moon's orbit in connection with changes in the apparent pattern of motion (Plummer, in press).

Teachers' Ideas Relating to Celestial Motion

Teachers' alternative ideas about elementary astronomy concepts suggest that their understanding may hinder their ability to design and implement appropriate instruction for their students. Surveys of preservice and practicing teachers suggest that most do not hold the scientific view for many sun-earth-moon concepts (Brunsell & Marcks, 2005; Schoon, 1995; Trumper, 2006). Mant and Summers (1993) concluded that the English elementary teachers in their study did not have a strong observational foundation and were attempting to work from "mental models" to formulate responses. A large fraction of both American and English teachers hold alternative ideas about the explanation for the day-night cycle, such as the sun moving around the earth (Atwood & Atwood, 1995; Mant & Summers 1993; Plummer, Zahm, & Rice, 2009; Parker & Heywood, 1998).

Theoretical Framework

Learning Progression Framework

In this paper, we begin to elaborate a learning progression for the conceptual area of celestial motion. This work builds on our previous work to elaborate how children may progress in their understanding of the apparent patterns of celestial motion observable from an earth-based perspective without delving into how children may develop the explanations for those observations (Plummer & Krajcik, 2008). Our work here is preliminary as we have only a small population from which to draw and test our ideas though we are also drawing heavily from our knowledge of the discipline and the literature.

Given that there is limited time to devote to any one area of science in K-8 school time, it is necessary to determine which "big ideas" will give students the necessary foundational knowledge to understand their world and continue their education (NRC, 2007). Big ideas hold broad explanatory power in the domain, make connections across isolated concepts, and are developed over time as learners understanding them in increasingly sophisticated ways (Anderson, 2008; Catley, Lehrer, & Reiser, 2005; Duschl, Schweingruber, & Shouse, 2007; Smith, Wiser, Anderson, & Krajcik, 2006). Designing science instruction around big ideas will help us weed out peripheral ideas and instruction that focuses on the rote memorization of disconnected facts. While the field is at the beginning of identifying what constitutes a "big idea" in each discipline, we argue that one big idea in astronomy is that observable phenomenon can be explained through the unobservable motions of the earth and moon (Plummer & Krajcik, 2008). Understanding of this big idea includes the ability to explain the apparent daily motion of the sun, moon and stars, explain how the seasonal change of the sun's path leads to an explanation for the seasons, and explain how the motion of the earth and moon relates to the phases of the moon.

A learning progression describes how students' initial ideas entering school can be built upon through instruction to reach a level of understanding that aligns with scientific views of the motions and properties of celestial bodies. According to Smith et al., learning progressions "describe successively more sophisticated ways of reasoning within a content domain" (2006, p. 3) and can be used to suggest how students may build upon their knowledge towards an expert understanding. The development of this progression follows the framework used to develop learning progressions on the atomic-molecular theory (Smith, Wiser, Anderson & Krajcik, 2004), evolution (Catley, Lehrer, & Reiser, 2004), environmental literacy (Anderson, 2008) and as outlined in Taking Science to School (Duschl et al., 2007). It is important to note that moving along a learning progression is not inevitable. Rather the learning progression is a possible description of how students may progress with good instruction.

Even though this proposed learning progression for celestial motion builds on our research and evidence from the literature about children's thinking, it is still only a *possible* description of how a learner may move through the successively more complex ways of thinking about these concepts (Smith et al., 2006). Anderson (2008) refers to this as the learning progression hypothesis – "although the development of scientific knowledge is culturally embedded and not developmentally inevitable, there are patterns in the development of students' knowledge and practice that are both conceptually coherent and empirically verifiable" (p. 11). Not all students will move through this progression in the same order, nor will they all achieve the scientific understanding. There remain considerable gaps in our understanding of how children actually progress in their understanding of celestial motion, especially in terms of the effect of instruction on these topics. Therefore, 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 a preliminary look at an area that should be investigated in significantly more depth.

Instructional Intervention Framework

A major piece of learning progression development is to identify instructional practices that will move students along a theoretical progression. Thus part of our work was to test a small instructional intervention's usefulness in this domain (this intervention will be referred to as Study A). A second part of the development utilized a curriculum already in place in a school district which will be described in more detail below (we will refer to this as Study B).

We considered several theoretical perspectives relating to how students learn particular to this domain as we designed instruction for Study A. As our previous literature review indicates, students lack an understanding of the earth-based perspective from which to develop explanations. To fully understand, children need to have an evidence-based perspective to explain (Plummer, in press, 2009; NRC, 1996). In this way we grounded our instruction in an inquiry-based model (though we did not follow through on the full enactment of an inquiry investigation). Developing children's understanding of apparent celestial motion requires that students acquire a repertoire of mental images that they can run through to model the daily motion of these objects. Prior research has found that children interacting with 3D planetarium-dome simulations (Plummer, 2009) and 2D personal computer based simulations (Bell & Trundle, 2008; Hobson, Trundle, & Sackes, 2009) have been successful in promoting understanding of observational astronomy topics. This supports our assertion that observations of the real sky will rarely be enough (unless extensive time and scaffolding is provided) to produce the same descriptive understanding for the patterns of celestial motion as well designed and supported simulations.

Dual coding theory suggests that combining verbal descriptions with kinesthetic and visual interaction with concepts may impact learning to a greater extent than using a single modality approach (Clark & Paivio, 1991; Plummer, 2009). This may be especially important in areas relating to celestial motion as children need to be carefully scaffolded in their development and use of models to explain observations. Attempting to make connections between unobserved rotations and orbits to patterns of apparent motion that occur on timescales of hours or days creates a cognitive load that is not easily juggled by the learner. Thus the use of physical models and kinesthetic (psychomotor) interaction has been successfully been explored in learners understanding apparent celestial motion (Plummer, 2009), phases of the moon (Hobson, Trundle, & Sackes, 2009; Trundle, Atwood, and Christopher, 2007), and seasons (Slater, Slater, & Morrow, 2008).

We also approached our instructional design from a constructivist perspective which recognizes that conceptual change requires students to actively engage in their prior knowledge and compare new ideas and models for their usefulness to explain observations (e.g. Duit & Treagust, 1998; Posner et al., 1982; Strike & Posner, 1992). Thus we considered those alternative conceptions students may have and a) develop ways to bring those ideas to the foreground in students' minds for comparison with new observations and models and b) design targeted activities and instruction to produce conflict with their naïve views. Finally, Vosniadou and Brewer's (1992, 1994) work on children's ideas in astronomy is highly illustrative of the ways in which children combine scientific concepts with their prior naïve world views to produce synthetic ways of understanding the world. This is not necessarily a negative as these synthetic models may be stepping stones towards more sophisticated ways of understanding through additional instruction (Duschl, et al., 2007).

Methodology

Subjects Characteristics and Setting

Study A: Eighteen third-grade students participated in the instruction from three different schools, as part of their gifted programs. Most students had visited the school district's planetarium prior to this instruction but had not received sustained instruction on these topics previously. Instruction took place in a separate classroom for gifted instruction. All three schools are part of the same suburban school district. Each elementary school serves approximately 400 students in grade K-3. Sixteen of the students completed both the pre and post-interviews; this data will be presented. Three schools were involved: three students at School 1, six students at School 2, and nine students at School 3 (these students are regularly taught by the second author of this study; the students in the other two schools have a different gifted teacher). Thirteen of these students were Caucasian; three were Asian. Nine students were male and seven were female. Average age during instruction was 8 years and 8 months.

Study B: Four 3rd-grade classrooms from the same school (School 3, described above) participated in Study B which took place in the same school district as Study A. Study B took place in the school year following Study A so there were no overlaps in the participants. Twenty-four students were randomly selected (split evenly by gender) to be interviewed before and after their standard astronomy curriculum (described below). Students were drawn from the full student population and may or may not have included identified gifted students (these were not specifically targeted in this study). All instruction was taught by the students' regular classroom teachers. Students were drawn from multiple classroom teachers to avoid some of the bias that may be caused by a particular teacher's approach in the classroom. Most students had visited the school district's planetarium during the previous school year but had not received sustained instruction on these topics.

Data Collection

Study A: Pre-instruction interviews were held approximately one month before instruction (because of winter vacation) while post-instruction interviews were completed approximately one week after the completion of instruction. The interview began with semi-structured interview questions covering concepts of apparent celestial motion and took place in a small dome with the child using a flashlight to represent the sun, moon or a star (based on interview used in Plummer (2009, in press)). This portion of the interview was audio taped and the students' demonstrations were drawn by the interviewer (first author). The second half of the interview had the children explaining what they demonstrated in the dome using physical models of the sun, earth and moon (based on interview protocol used in Plummer, Zahm, & Rice (2009)). This portion of the interview was recorded on video. A list of interview questions in included in Appendix A.

Study B: Pre-instruction interviews were held approximately 1-2 weeks before the 6 week unit began while post-instruction interviews were completed approximately three weeks after completion of instruction (because of winter vacation). The same interview procedure and protocol were used as with Study A (described above).

Instructional Design

Study A: The instruction used in Study A was designed and taught by the co-authors of this paper, as part of the students' gifted programs. Approximately 1 month before instruction, students were asked to complete a series of observation and report their observations on a worksheet. These questions are included in Table 1.

Table 1. Student observing log prior to instruction

OBSERVATIONS OF THE SKY
When you come home from school today, before you go inside, look for where the sun is. You might not see the sun directly, but you can tell by what part of the sky is the brightest. Look for the moon, too!
Then in the morning, the next day, when you walk outside to go to school, look for where the sun is. You might not see the sun directly, but you can see where the sun is rising. Look for the moon too!
Use the observation journal provided to write down your observations. These observations should be made for 2-3 days. Then you can answer the questions at the bottom of this sheet.
Questions: Please circle your answers 1. Was the sun in the same place in the morning and the evening? YES NO 2. Was the sun high or low in the sky in the morning? HIGH LOW 3. Was the sun high or low in the sky in the evening? HIGH LOW 4. Was the sun higher in the morning or the evening? MORNING EVENING 5. Was the sun in the same part of the sky in both the morning and evening, or was it in different places?

SAME PLACE DIFFERENT PLACES

6. Could you see the moon in the morning?

   YES NO

7. Could you see the moon in the evening?

   YES NO

8. What did it look like? You can draw a picture if you want.

Instruction was approximately 100 minutes across two consecutive days. Because nearly all of the students understood that the sun appear to rise in the east and set in the west because of the earth's rotation (as found in the pre-test) the first 30 minutes of the class are mostly review and a chance for the students to become comfortable with the instructional design and familiar with watching the computer program Stellarium (http://www.stellarium.org). We began with the apparent motion of the sun using both kinesthetic descriptions in the classroom (using physical direction markers, observations of the actual sun out the window, and the students physically mimicking the path of the sun with their arms) and observations of the sun's motion over time using the computer-based planetarium program Stellarium. Students were asked to kinesthetic model the earth's rotation (by spinning on their own axis) as well as work with earth globes was used to explain the sun's apparent motion. The instructor and the students then discussed the students' prior observations of the moon and observed the moon's apparent motion on the computer using Stellarium. The lesson ended with students drawing a picture demonstrating their idea of why the moon appears to rise and set.

Lesson two began with a review using Stellarium followed by students "sharing out" their drawings. The students' ideas were discussed and physical models were used to test possible reasons, including the scientific model. The students use the models to understand the slow orbit of the moon relative the rotation of the earth. We discussed the size and distance to the stars with the students and kinesthetically modeling why the stars appear to rise and set. Finally, students drew a new picture representing their idea about why the moon and stars appear to rise and set.

<u>Study B:</u>

Third grade teachers in this school district are requested to teach science (or social studies as units on these topics alternate) three days a week. The district's third grade astronomy unit includes 19 days worth of lessons (approximately 6 weeks). The major concepts included in this unit include: explanation of how the sun illuminates the moon, the rotational/revolutionary relationships among the sun, earth and moon, explanation of the phases of the moon, and characteristics of the moon's surface. The unit instruction is described as follows (Colonial School District, 2005):

> Students examine the theme of Patterns and Cycles through a study of the phases of the Moon. First, they read three myths that explain (in a non-scientific manner) why the appearance of the Moon changes throughout a month's time. Students

> then explore how the Moon shines, why the Sun and the Moon appear to be the same size despite their different sizes and how the different phases of the Moon occur. The students examine impact craters and the variables that affect their creation. The history of space travel is studied and models of solar and lunar eclipses are observed by students. Finally, students pick one of the three Moon myths and explain the real scientific facts behind the story told. (p. 5)

The concepts relevant to this celestial motion learning progression appear in Activities 2 (2 days), 4 (3 days), and Activity 8. In Activity 2 students are asked to find the correct definition of vocabulary words (using a dictionary when needed): axis, rotate, revolve, orbit, ellipse, and satellite. Groups of students demonstrate the definitions using balls, globes, strings, etc. The teacher guides students to write or draw the definitions during a class discussion. Students read a two page document defining the concepts of rotation and revolution with respect to the earth and moon's motion and then revisit their previous definitions. In Activity 4 students are asked to make a prediction of the cycle of the phases of the moon. Students are then guided to model the phases of the moon using a lamp and a Styrofoam ball. Finally, students are asked to observe and record the moon's appearance in their own moon calendar. In Activity 8, the teacher models solar and lunar eclipses using a flashlight, earth globe, and small moon-ball while the students draw and label components of the eclipses.

No attempt was made to verify the extent to which the teachers follow the curriculum in each of the classrooms. Rather, our data collection was primarily for the purpose of identifying the current extent of learning based on teachers' normal practices in the school district.

Analysis

Primary categories: Each aspect of celestial motion was broken down into multiple categories describing aspects of the students' descriptions (e.g. the sun's path, the sun's rising and setting directions, etc.). A coding scheme for these categories was developed based on previously reported descriptions of children's ideas about apparent and actual celestial motion (Plummer, 2009, in press; Plummer, Zahm, & Rice, 2009) and was modified when necessary to accommodate new ideas uncovered within this sample. This initial coding scheme is included in Appendix B. Both authors independently coded five pre and five post interviews to establish external validity of the coding system resulting in an inter-rater agreement of 92.7%. For all discrepancies, we reviewed the interviews, reached a consensus, and clarified the coding document when necessary.

Construction of the Learning Progression

The learning progression was initially created based on the pre and post-results of the third grade gifted students. The same analysis procedure was then used with the whole third grade class. These students' ideas were compared to the learning progression and improvements were made to account for the range of ideas they expressed.

Initial Creation and Testing: Third Grade Gifted Intervention

Part I – Coding of students' explanation of each celestial category's apparent motion

Secondary codes were created to classify three new secondary categories:

- Sun model: How does the student describe the sun's pattern of apparent motion and then explain that motion?
- Moon model: How does the student describe the moon's pattern of apparent motion and then explain that motion?
- Stars model: How does the student describe the stars' pattern of apparent motion and then explain that motion?

The secondary codes were defined by the primary codes describing individual aspects of the students' understanding. For example, one new code (representing a non-normative conception for the explanation) is "Student gives a generally accurate description of the sun's apparent motion and explains this with the earth's revolution around the sun." The secondary codes were initially developed based on the nature of the students' responses in Study A; additional codes were identified as the same analysis was applied to Study B by uncovering new combinations of primary codes expressed by the students.

Part II – Development of learning progression considering the overall understanding of celestial motion

In the next stage of development, we created the learning progression by combining analysis of the discipline with an assessment of each student's overall understanding of the celestial motion. Our goal was to develop a learning progression that ties together aspects of celestial motion at an elementary level. First, a rough outline of the levels was developed by looking at the potential scientific descriptions to anchor the progression (scientific world view) and descriptions based on personal observations (naïve world view) to anchor the initial end of the progression. Previous work on the apparent celestial motion progression (Plummer & Krajcik, 2009) and an understanding of the topics covered in the interviews helped guide this initial outline.

The intermediate levels are more complex as these represent a variety of synthetic world views (Vosniadou & Brewer, 1992, 1994): students combining both naïve and scientific aspects in their celestial motion descriptions. An iterative approach was used to develop these levels based on examining the secondary codes and looking for trends first among the 16 students from Study A and the 24 students in Study B. An early trend we recognized was the strong tendency among students to have an accurate (or partially accurate) description and explanation of sun concepts and not moon and stars but not the other way around. This helped establish the level between naïve to scientific (from least to most sophisticated). We also looked for ways that earlier levels contained ideas that could be built upon and made more sophisticated when moving to the higher level. For example, students who used both the earth's rotation and other inaccurate explanations (such as the sun going around the earth) to explain the sun's apparent motion were placed at a lower level (more naïve) than students who only used the earth's rotation in their explanation of the sun's apparent motion but at a higher level than students who used only non-normative explanations (such as that the sun is actually moving).

Next, all students were re-examined, both pre and post, and classified on the initial learning progression using the secondary codes. Instances where students could not be unambiguously categorized to a level led to either refining specific levels or creating new levels on the progression. Our progression may not contain all possible descriptions of students' understanding but it outlines most of the primary ways students may understand celestial motion. Future research may lead us to add or modify to accommodate additional synthetic world views as well as to extend the end anchor to more advanced concepts of celestial motion. The learning progression is outlined in Table 2 (more detail on each level will be expressed in Table 3).

Table 2 – Learning Progression for Celestial Motion

Level 1 – Naïve World View **Defining characteristic**: Children do not use the scientific concept of the earth's rotation in their explanations for observable phenomenon. Pre-observational view: The child cannot describe the sun or moon's rising or setting motion. Observational view of sun and moon: Their descriptions of the sun and moon's apparent daily rising/setting motion may or may not be scientific. They might say that the sun and moon rise and then set on the opposite side of the sky. Or they may say that the sun and moon rise and set in the same place. Stars: Stars do not appear to move or only in small motions.
Level 2 – Synthetic World View **Overall defining characteristic**: Students use aspects of the scientific explanations (rotation of the earth, orbit of the moon, orbit of the earth) but in ways that do not result in a fully scientific description of celestial motion.
Sub-Level 2.1 – Synthetic: Non-scientific use of explanations
Defining characteristic: Students use aspects of a scientific explanatory model inaccurately. These students all have inaccuracies in their explanation of the sun's daily apparent motion. They almost always will also have inaccuracies in the moon and stars as well. Their explanations include revolution of the earth, rotation switches direction or inaccurate description of sun's daily apparent motion.
Sub-Level 2.2 – Synthetic: Combining non-scientific explanations with the earth's rotation **Defining characteristic**: Students use an accurate description of the earth's rotation to explain the sun's apparent motion but combines this with an additional inaccurate explanation or inaccurate description of sun's apparent motion. The student does not use a completely

scientific explanation of the moon and stars' apparent motion.

Sub-Level 2.3 – Synthetic: Accurate use of rotation for sun's apparent motion

Defining characteristic: Students use an accurate description of the earth's rotation to explain an accurate description of the sun's apparent motion. The student does not use a completely scientific explanation of the moon and stars' apparent motion.

Level 3 – (Basic) Scientific world view

Overarching defining characteristic: Student uses the earth's rotation to explain relatively accurate descriptions of the sun, moon and stars' apparent motion.

Sub-Level 3.1 – The Earth's Rotation for All Objects

Defining characteristics: The student describes the sun, moon and stars as rising and setting in the same direction across the sky (there may be a lack of sophistication in the path details but they generally follow the scientific trend for daily motion). The child uses the earth's rotation to explain these motions. But there are still inaccuracies in description of the moon's orbit or how that orbit is involved in the moon's apparent motion.

Sub-Level 3.2 – The Earth's Rotation and Moon's Orbit

Defining characteristics: The student describes the sun, moon and stars as rising and setting in the same direction across the sky (there may be a lack of sophistication in the path details but they generally follow the scientific trend for daily motion). The child uses the earth's rotation to explain these motions. The child understands that the moon orbits the earth once a month but that this is not the cause of the moon's daily rising and setting.

The progression is designed to show how students may move from a naïve view towards a scientific view of how actual motions of celestial objects and our position on the earth influences the patterns of motion we can see. However, there are many ways students could describe the combination of the earth/sun/moon/stars motions or lack of motion from an earth-based perspective and solar-system view. So in the development of this progression, we chose to highlight characteristic features of children's models that would help teachers and curriculum developers plan to work with these ideas and to see how intermediate levels can still represent a positive step towards scientific understanding. At this time, the progression is less detailed than a previously developed progression that focused only on the apparent motion (Plummer & Krajcik, 2009).

Analysis of Instruction based on the Celestial Motion Learning Progression

The next phase of developing the learning progression is both measure the impact of the instruction in Studies A and B and to assess whether the progression provides a useful scale to use in looking for improvement. Table 3 elaborates our learning progression for celestial motion, describing in more detail the characteristics of students' ideas in each level and sub-level. Appendix C lists the specific secondary codes that were used to assign students to each level of the progression. The lowest level represents a level of understanding seen in previous research but not the students in either Studies A or B (Plummer, in press).

Table 3 - Learning Progression for Celestial Motion (Gifted: N=16; Regular: N=24)

	Gifted		Regular	
	Pre	**Post**	**Pre**	**Post** [1]
Level 1 – Naïve world view	**2** **13%**	**1** **6%**	**12** **50%**	**3** **13%**
A Student cannot describe the sun as rising and setting and explanation not based on descriptive motion. The moon may or may not move but this motion is not a smooth rising and setting. The stars do not rise and set and, other than shooting stars or small motions, do not move.	0	0	0	0
B Student believes that the sun and moon appear to rise and set (or go up/down) because of their own motion (these descriptions may not be similar to the scientific description). Stars do not move, move a little bit, or move due to their own motion. The earth does not move.	1	0	9	0
C Children understand that the sun and moon rise and set on opposite sides of the sky and in the same direction. But they use the object's own motion (revolution around the earth) to explain. Stars do not move, move a little bit, or move due to their own motion. The earth does not move.	1	1	3	3
Level 2 Synthetic world view	**13** **81%**	**7** **44%**	**12** **50%**	**19** **79%**
Sub-Level 2.1 –Non-scientific use of explanations	*1* *6%*	*1* *6%*	*3* *13%*	*3* *13%*
A Student uses the earth revolving around the sun explain a generally accurate description of the sun's apparent motion. Descriptions of the moon and stars' apparent motion, and explanations, also contain inaccuracies.	1	0	0	0
B Student gives an inaccurate description of the earth's rotation and may include other inaccurate explanations (such as sun's own motion or revolution) to explain sun's apparent motion. Descriptions of the moon and stars' apparent motion, and explanations, also contain inaccuracies.	0	1	3	3
Sub-Level 2.2 – Combining non-scientific explanations with the earth's rotation	*3* *19%*	*1* *6%*	*6* *25%*	*8* *33%*

C Student uses a generally accurate description of the earth's rotation to explain an inaccurate description of the sun's apparent motion. Student may also include other inaccurate explanations (such as the sun actually moving). Descriptions of the moon and stars' apparent motion, and explanations, also contain inaccuracies.	1	0	6	4
D Student uses the earth's rotation as well as other inaccurate explanations (such as revolution) to explain a generally accurate description of the sun's apparent motion. Descriptions of the moon and stars' apparent motion, and explanations, also contain inaccuracies.	2	1	0	3
E Student uses the earth's rotation as well as other inaccurate explanations for the generally accurate description of the sun's apparent motion. Student explains the generally accurate description of the moon OR stars' apparent motion using the earth's rotation.	0	0	0	1
Sub-Level 2.3 – Accurate use of rotation for sun's apparent motion	*9* *56%*	*5* *31%*	*3* *13%*	*8* *33%*
F Student uses the earth's rotation to explain a generally accurate description of the sun's apparent motion but not the moon and stars.	5	2	1	4
G Student uses earth's rotation to explain a generally accurate description of the sun's apparent motion and either the moon or stars, but not both. At this level, students are beginning to make the connection between the earth's rotation and observed patterns of motion but have not applied this to all possible objects (sun, moon, and stars).	4	3	2	4
Level 3 – Scientific world view	**1** **6%**	**8** **50%**	**0** **0%**	**1** **4%**
Level 3-A The child describes the sun, moon and stars as rising and setting in the same direction across the sky (there may be a lack of sophistication in the path details but they generally follow the scientific trend for daily motion). The child uses the earth's rotation to explain these motions. But there are still inaccuracies in description of the moon's actual motion or how that motion is involved in the moon's apparent motion.	1	3	0	1
Level 3-B The student describes the sun, moon and stars as rising and setting in the same direction across the sky (there may be a lack of sophistication in the path details but they generally follow the scientific trend for daily motion). The child uses the earth's rotation to explain these motions. The	0	5	0	0

child understands that the moon orbits the earth once a month but that this is not the cause of the moon's daily rising and setting.				

[1] One student could not be classified clearly into one level in post-instruction.

With students drawn from only one grade band, there is a limitation to which we can test this progression. We have matched this with a particular focus on using the earth's rotation to explain the daily motion of the sun moon and stars. We can see, however, that the two groups of students (gifted versus regular classroom) show up as different populations on the progression. The data suggests that half of the regular third grade students are at a naïve level without instruction while a much smaller percentage (13% in Study A) of the gifted students hold naïve views of celestial motion initially.

We can also use this progression to describe how the two different instructional interventions (Study A: a targeted 3-day investigation of celestial motion taught by astronomy-experts; Study B: a 6-week unit covering celestial motion as a subset of a study of the moon taught by regular elementary teachers) can move these two populations along the learning progression. In Study A, 11 of 16 students (69%) moved towards the scientific levels on the progression. Four students did not change their level and one regressed down a level. One of the strengths of using the learning progression methodology with this conceptual area is that we can see that half (50%) of the students are now using the earth's rotation to explain the daily motion of the sun, moon and the stars compared to only one student prior to the intervention. In Study B, analysis using the learning progression shows that 18 students improved (75%) while 3 stayed at the same level and 1 regressed (2 could not be clearly determined). While the improvement is promising for the curriculum approach and would appear to be on par with the outcomes of Study A, a closer look at the learning progression reveals that this represents a shift from naïve to synthetic rather than to a fully scientific use of the concepts.

Because the gifted students started in a substantially different distribution on the learning progression compared to the regular third grade population, we do not argue here that the targeted instruction of Study A would have had the same effect on the other students. However, the results are suggestion of the power of the techniques and suggest to us that these should be studied further in the whole third grade population. Perhaps the results suggest that after participating in the third grade astronomy curriculum the regular students would be more receptive to instruction similar to Study A and would show similar outcomes as the gifted students.

Professional Development Based on Celestial Motion Learning Progression

The purpose of creating the instruction for the gifted third grade students and then assessing the impact of that instruction was to use students' ideas in the preliminary development of a celestial motion learning progression and to test out instructional ideas for the purpose of presenting these strategies to the district's third grade teachers through targeted professional development (Plummer & Slagle, 2009). The purpose of collecting and analyzing the interview data from the regular third grade curriculum was to: identify students' placement on the learning progression before instruction, identify the extent to which the current curriculum moves students along a learning progression, and to use this information (in combination with our earlier experiment with the gifted third grade students) to propose modifications to the existing curriculum. In this section, we will describe how the results of the two studies and the development of the learning progression will become the foundation of a professional development to be conducted in the school district this fall.

Through the use of the learning progression in professional development, we hope to educate teachers on their students' likely initial ideas about celestial motion, to persuade teachers to adopt new activities that will improve their students' understanding of these foundational concepts, to improve connections between their use of the planetarium with classroom instruction, and to help teachers understand the importance of improving students' ideas in this domain. A three-day (2 hours each day) professional development is planned for Fall 2009. Two days will be devoted to the concepts of celestial motion described in this manuscript. Included in these two days will be engagement in three new activities to replace the two days of "Activity 2" covering the definitions of words relating to celestial motion. The third day will focus on concepts relating to the explanation for the seasons. This day was added to the professional development because the district recently chose to add the seasons to the third grade curriculum. Through discussions with some of the third grade teachers they expressed their interest in learning more about how to teach children about the seasons as they had not received additional training on this topic. The professional development will take place in the District's planetarium in order to demonstrate to the teachers how they can make connections between a visit to the planetarium and their classroom instruction.

At this point we are only suggesting a relatively minor alterations to the existing curriculum (changing one activity to improve knowledge of celestial motion) and re-adjusting aspects of another activity (phases of the moon) as well as hoping to improve the teacher's integration of a lesson in the planetarium with their overall classroom instruction. This limited change to their practice is a strategic move that we hope helps the teachers provide the foundation that students need while also matching the interests and limitations of the teachers. There is limited time available for working with the teachers. Celestial motion concepts are only a part of a unit which primarily focuses on moon features and phases of the moon (though we will emphasize that phases of the moon concepts build on and are therefore more advanced than our target celestial motion concepts). And teachers are likely to have had limited training in astronomy.

Taking Science to School concludes that, based on the a review of pertinent literature, successful teacher education will (Duschl et al., 2007):

1. Reflect a clear focus on the improvement of student learning in a specific content area that is grounded in the curriculum they teach.

2. Focus on the strengths and needs of learners in the setting and evidence about what works drawn from research and clinical experience.
3. Emphasize the collective participation of groups of teachers, including opportunities for teachers from the same school, department, or grade level.
4. Provide teachers with a coherent view of the instructional system (e.g., helping teachers see connections among content and performance standards, instructional materials, local and state assessments, school and district goals, and the development of a professional community). (p. 307)

The two-day celestial motion professional development is designed around these principles. Teams of teachers from three schools in the district will be brought together. First, teachers will be shown of different ways that students understand these concepts. This will include video of children and adults explaining their understanding of the concepts and specific examples drawn from interview transcripts. These will be used to help the teachers understand the basic levels of the learning progression: naïve, synthetic, and scientific. Second, we will present the basic version of the learning progression (see Table 2) and explain how this relates to their school district's students' understanding of these concepts. As we work through the basic levels of the learning progression (naïve, synthetic, scientific) we will highlight through demonstration and discussion the aspects of these levels that can be built on towards the next more sophisticated level of understanding while at the same time addressing challenges presented by some of their non-normative ideas. We will present a summary of our findings of their students' pre/post instruction results with relation to the learning progression to help the teachers understand where their students are starting from and where they end up following a traditional enactment of their curriculum. Third, teachers will participate in working through the new activities and observe how these relate to the topics that will be covered in a planetarium visit. We will use the results from our work with the gifted third grade classes to explain how using the new activities (based on that previous pilot testing) can move students along the celestial motion learning progression. We will examine how the new activities fit within the existing curriculum and connect to other concepts. Finally, we will discuss with the teachers how moving along the celestial motion learning progression will prepare students understand additional unit goals: phases of the moon and seasons.

One aspect of our professional development work is to describe trends seen in students' initial ideas to help teachers understand where their students are beginning on the learning progression. We have found that many third grade students use the sun's own "up and down" motion to describe its apparent motion – even when they are familiar with the concept of the earth's rotation. There appears to be a disconnect between knowing rotation and using the concepts to describe what we can see from the earth. This trend crosses into how students explain the moon and the stars' apparent motion. Even when students know that the earth's rotation explains the sun's rising and setting, they do not accurately apply this concept to other celestial objects. Thus our research suggests that without targeted instruction, students will not learn to apply the earth's rotation universally to our earth-based perspective and thus not deeply understand the concept of daily celestial motion. However, at the same time it may be important to first focus on developing a strong connection between the sun's apparent motion and the earth's rotation and then *apply* this concept explicitly to the moon and stars. Perhaps not surprisingly, students appear to acquire the scientific concept of the sun-earth connection much more readily than other concepts in this domain. Other trends in students' ideas about celestial motion may influence what and how they learn. For example, students who believe that the moon does not actually move appear to be more likely to use the earth's rotation to explain the moon's daily rising and setting.

Conclusions

This manuscript describes a work-in-progress towards creating an empirically based learning progression that includes descriptions of strategies that are successful in moving students along such a progression. The learning progression we have build describes the range of ideas held by students ranging from naïve descriptions and explanations of daily celestial motion through the scientific description of daily celestial motion. The progression was built through an analysis of the scientific use of these concepts as well as the descriptions and explanations given by two different populations of third grade students (gifted and general). We have also analyzed two instructional interventions and demonstrated how the progression can be used to describe students' trajectory towards the scientific perspective.

Our development of this learning progression is limited by the use of only one age of students (third grade) drawn from a single school district. Our work would be improved by drawing from a wider range of grades and from students in different locations, backgrounds, and curricula. The end-point ("scientific world view") of the progression only reaches an understanding of daily celestial motion and knowledge of the moon's orbit. By middle school, many state and national standards (AAAS, 1993; NRC, 1996; Palen & Proctor, 2006) recommend that students learn to explain seasonal changes in the sun's apparent motion to explain the seasons, seasonal changes to the stars' appearance in the sky, and the phases of the moon. All of these rely on scientific description of celestial motion presented in this manuscript. Thus our work here only represents the first few rungs of a learning progression on celestial motion, not the full development from K-8.

This fall, we will be conducting a professional development based on this learning progression analysis with third grade teachers, including the teachers of the students in Study B. We will then use the learning progression to analyze how three new instructional conditions move students along the progression: planetarium instruction only (1 lesson focusing on apparent celestial motion), classroom instruction only (regular curriculum but taught by teachers who participated in the professional development), classroom and planetarium instruction (teachers participated in the professional development). This will allow us to further characterize the importance specific instructional interventions in moving children along a learning progression. We will also use this future investigation to extend our learning progression to include phases of the moon concepts.

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Appendix A: Interview Questions

Versions of this protocol have been used in previous studies (Plummer, in press, 2009; Plummer, Zahm, & Rice, 2009).

Apparent celestial motion

The students will use a flashlight to demonstrate their answers in a mini-dome:

1. Sun's apparent motion today
    a. Can you show me where the sun is first thing in the morning?
    b. Can you show me the sun's apparent motion throughout the day?
    c. What happens at the end of the day?
    d. Where is the sun at noon?
    e. Would that be directly over your head?
2. Motion of the moon
    a. Does the moon appear to move across the sky?
    b. (If the moon appears to move) Can you show me what that looks like?
    c. (If the moon appears to rise and set) When does the moon rise? When does the moon set?
    d. Are there times when we cannot see the moon? Why can't we see it? Can you think of any other reasons?
3. Motion of the stars
    a. You showed me the motion of the sun and the moon. Do the stars appear to move at night too?
    b. (If yes) Pretend the flashlight is showing one bright star. Can you show me the motion of that star?
    c. Do we see the same stars all night long? Why or why not?
    d. What happens to the stars when the sun comes up in the morning?

Actual celestial motion

Ask the subjects to use a model of the sun (a ball), the earth (a small globe), and moon (a small ball) to describe why they showed the sun, moon and stars' apparent motion. Have the student put a sticker on the earth to show his/her location.

1. Can you use these objects to explain why the sun appears to move across the sky as you showed in the dome? (Prompt the student to indicate when sunrise, noon and sunset are occurring.)
2. Can you use these objects to explain why the moon appears to move (or not move) like you showed in the dome?
    a. Can you use these objects to explain why we can't see the moon some of the time?
3. Where would the stars be in this model? When would we be able to see them?
4. Can you use these objects to explain why stars (do not) appear to move?

Appendix B: Primary Categories - Coding Document

1. **Sun-Opp**: Does the sun rise and set on opposite sides of the sky?

Accurate: A smooth path that rises and set more than 45 degrees apart.

Non-normative: Any other type of path, including paths with sharp turns, or that goes straight up and down.

2. **Sun-EW:** Does the sun rise in the east and set in the west?

Accurate: Sun rises in the eastern hemisphere of the sky and sets in the western hemisphere (e.g. rising SE and setting SW is accurate).

Non-normative: Any other combination of rising and setting positions.

3. **Sun-Zen1:** Does the sun pass below the zenith? Base answers on the initial questions about the sun's path. (Based on responses for the sun's path on THIS DAY.)

Accurate: Sun does not pass through the circle at the top of the dome AND the student says that the sun does not pass directly overhead.

Partially accurate: Inconsistent – Indicates both that the sun is below the zenith but also that it goes through the zenith through a mis-match in their verbal response (e.g. no it is never overhead) and demonstration (e.g. passing through the zenith)

Non-normative: Sun passes through the zenith (both in demonstration and verbal answer).

4. **Sun-Zen2**: Does the sun ever pass through the zenith? (Now students are asked if the sun EVER passes overhead, not just on the day that they are being questioned about.)

Accurate: No, both in demonstration and verbal responses.

Partially accurate: Inconsistent between verbal response and visual demonstration.

Non-normative: Yes in any of the demonstrations or verbal responses.

5. **Moon-move:** Does the moon appear to move?

Accurate: A verbal response of "yes" or description of a path

Non-normative: A verbal response of "no" or "I don't know"

6. **Moon-Opp:** Does the moon rise and set on opposite sides of the sky?

Accurate: A smooth path that rises and set more than 45 degrees apart.

Non-normative: Any other type of path, including paths with sharp turns, or that goes straight up and down.

7. **Moon-EW:** Does the moon rise in the east and set in the west?

Accurate: Moon rises in the eastern hemisphere of the sky and sets in the western hemisphere (e.g. rising SE and setting SW is accurate).

Non-normative: Any other combination of rising and setting positions.

8. **Moon-Sun:** Does the moon follow the same type of path as the sun?

Accurate: Same direction, same overall appearance and angle of path as the sun.

Non-normative: Paths are different in form.

9. **Stars-Move:** Do the stars appear to move?

Accurate: A verbal response of "yes" or description of a path

Non-normative: A verbal response of "no" or "I don't know"

10. **Stars-Path:** Do the stars appear to follow a smooth path in a continuous motion?

Accurate: Motion is smooth, in one direction, and continuous. This could include rising and setting, a smooth arc around the sky, or a circular motion.

Non-normative: Could include moving in multiple directions, many stars in many directions, or no movement. Also includes saying the stars appear to move but not demonstrating that motion. Also includes answers of "I don't know."

11. **Stars-Opp:** Do the stars appear to rise and set on opposite sides of the sky?

Accurate: Demonstrates that a star rises and sets on opposite sides of the sky and says that the stars rise and set (if asked).

Partially accurate: Either does not demonstrate rising and setting but answers "yes" when asked if they rise and set, or demonstrates that a star rises and sets but answers "no" when asked if stars rise and set.

Non-normative: Stars do not appear to rise and set.

12. **Stars-EW:** Do the stars appear to rise in the east and set in the west?

Accurate: Demonstrates that a star appear to rise in the eastern side of the sky and set in the western side of the sky.

Non-normative: Any other demonstrations or stars do not appear to move

13. **Stars-Diff:** Do we see different stars throughout the night?

Accurate: Requires an accurate answer (with an accurate explanation)

Non-normative: Either we do not see different stars or the explanation is incorrect

14. **Stars-Day:** Are the stars still in the sky during the daytime?

Accurate: Student believes that the stars are still in the sky during the day. (Explanation does not have to be accurate but put this in the justification.)

Non-normative: Student indicates that the stars are not in the sky during the day.

29. **Rotation:** Does the student accurate describe and/or demonstrate the concept of the rotation of the earth?

Accurate: Student clearly demonstrates that the earth rotates on its axis (or gives an accurate verbal description that cannot be confused with other concepts)

Non-normative: Does not include a demonstrate or clear explanation of rotation

30. **ExSun:** Does the student use the rotation of the earth to explain why the sun appears to move across the sky?

Accurate: Student models the earth rotating (in one direction) when asked why the sun appears to move. Does not include other motions to explain the sun's motion.

Non-normative: Student uses other kinds of motion (and may also include rotation) to explain why the sun appears to move.

31. **ExMoon:** Does the student use the rotation of the earth to explain why the moon appears to move across the sky?

Accurate: Student models the earth rotating (in one direction) when asked why the moon appears to move. Does not include other motions to explain the moon's motion.

Non-normative: Student uses other kinds of motion (and may also include earth's rotation) to explain why the moon appears to move. Or says that the moon does not appear to move.

32. **Orbit:** Does the moon orbit the earth about once a month?

Accurate: The moon orbits the moon once a month

Partially Accurate: The moon orbits the moon but in less than 27 days or more than a month

Non-normative: Any other response

33. **Moon-visible:** Does the student recognize that sometimes the moon is not visible because it is on the other side of the earth?

Accurate: Says or demonstrates that the moon is on the other side of the earth

Non-normative: Any other response – list in Justification

34. **ExStars:** Does the student use the rotation of the earth to explain why the stars appear to move across the sky?

Accurate: Student models the earth rotating (in one direction) when asked why the stars appears to move. Does not include other motions to explain the stars' motion.

Non-normative: Student uses other kinds of motion (and may also include earth's rotation) to explain why the stars appears to move. Or says that the stars do not appear to move.

35. Where are the stars?

	A. Farther away than the sun and moon
	B. Sun are closer and some are farther than the sun and moon
	C. Farther than the moon but closer than the sun
	D. Closer than both the sun and moon
	E. Same distance as sun and moon.
	F. Around the moon
	Unknown/unclear

Appendix C: Secondary Categories (Categories for Student Connections between Apparent Motion and Actual Motion)

None of these categories consider the accurate use of direction. In other words, a "generally accurate" refers to a smooth path across the sky but does not need to go from E to W.

The Sun

Sun-A1	Sun-A1: Student gives a generally accurate description of sun's motion and explains with the earth's rotation.
Sun-A2	Sun-A2: Student gives inaccurate description of the sun's rising and setting and uses the earth's rotation to explain this.
Sun-B1	Sun-B1: Student gives generally accurate description of sun's motion but explains with earth's rotation and the earth revolving around the sun.
Sun-B1-B	Sun-B1-B: Student gives an inaccurate description of sun's motion and explains with earth's rotation and the earth revolving around the sun.
Sun-B2	Sun-B2: Student gives generally accurate description of sun's motion but explains with inaccurate description of earth's rotation and the earth revolving around the sun.
Sun-B2-B	Sun-B2: Student gives an inaccurate description of sun's motion and explains with inaccurate description of earth's rotation and the earth revolving around the sun.
Sun-B3	Sun-B3: Student gives a generally accurate description of the sun's motion and explains with the earth's revolution around the sun.
Sun-C1	Sun-C1: Student gives generally accurate description of sun's motion but explains with earth's rotation and the sun revolves around the earth.
Sun-C1-B	Sun-C1-B: Student gives an inaccurate description of sun's motion and explains with earth's rotation and the sun revolves around the earth.
Sun-C2	Sun-C2: Student gives generally accurate description of sun's motion but explains using the sun going around the earth.
Sun-D1	Sun-D1: Sun moves up/down because sun is actually moving up/down.
Sun-D2	Sun-D2: Student gives inaccurate description of sun's RISING AND SETTING motion and explains with sun is actually moving up/down.
Sun-D3	Sun-D3: Student gives inaccurate description of sun's motion THAT DOES NOT INCLUDE RISING/SETTING and explanation includes the sun's own motion.

The Moon

Moon-A1	Moon-A1: Generally accurate description of the moon's apparent motion and uses the earth's rotation to explain. Moon orbits once a month.
Moon-A1-B	Moon-A1-B: Generally accurate description of the moon's apparent motion and uses the earth's rotation to explain. Moon's orbit is not a month.
Moon-A2	Moon-A2: Generally accurate description moon's apparent motion but uses earth's rotation and moon's 28 day orbit to explain daily motion.
Moon-A3	Moon-A3: Inaccurate description of moon's apparent motion but uses earth's rotation to explain. Moon orbits once a month.

Moon-A4	Moon-A4: Moon does not appear to move but uses earth's rotation and moon's 28 day orbit to explain daily motion.
Moon-B1	Moon-B1: Generally accurate description of the moon's apparent motion and uses the earth's rotation but the moon does not orbit and/or stays on opposite side from the sun.
Moon-B2	Moon-B2: Student gives inaccurate description of moon's motion and uses the earth's rotation but the moon does not orbit and/or stays on opposite side from the sun.
Moon-B3	Moon-B3: Moon does not appear to move but uses earth's rotation and moon does not orbit.
Moon-B4	Moon-B4: Generally accurate description of the moon's apparent motion but uses an inaccurate description of the moon's rotation. Moon's orbit may or may not be accurate.
Moon-C1	Moon-C1: Generally accurate description moon's apparent motion but uses earth's rotation and moon's 24 hour orbit to explain.
Moon-C2	Moon-C2: Generally accurate description moon's apparent motion but uses earth's rotation and moon's 24 hour orbit to explain. And Moon is always opposite Sun.
Moon-C3	Moon-C3: Generally accurate description of moon's apparent motion but uses earth's rotation and moon's up/down motion. Moon does not orbit.
Moon-C4	Moon-C4: Inaccurate description of moon's apparent motion but uses earth's rotation and moon's up/down motion. Moon does not orbit.
Moon-D1	Moon-D1: Generally accurate description moon's apparent motion but uses moon's 28 day orbit to explain daily motion.
Moon-D1-B	Moon-D1-B: Inaccurate description moon's apparent motion but uses moon's 28 day orbit to explain daily motion.
Moon-D2	Moon-D2: Generally accurate description moon's apparent motion but use moon's orbit to explain. Orbit is not close to a month.
Moon-D3	Moon-D3: Student gives inaccurate description of moon's motion and uses moon's orbit to explain. Orbit is not close to a month.
Moon E1	Moon-E1: Generally accurate description of moon's apparent motion and explains that moon moves up and down. Moon does not orbit.
Moon E2	Moon-E2: Student gives inaccurate description of moon's apparent motion and explains that moon moves up and down. Moon does not orbit.
Moon-F1	Moon-F1: Student does not think moon appears to move or actually moves.

The Stars

Stars-A1	Stars-A1: Accurately describes stars' apparent motion and uses earth's rotation to explain this.
Stars-A2	Stars-A2: Accurately describes stars' apparent motion (except for seeing different stars during the night) and uses earth's rotation to explain this.
Stars-A3	Stars-A3: Stars appear to move, but student gives inaccurate description of stars' motion and uses earth's rotation to explain this.
Stars-B1	Stars-B1: Accurately describes stars' apparent motion and uses earth's rotation and orbit around the sun to explain this.

Stars-C1	Stars-C1: Stars do not move; student uses earth's rotation to explain that stars only set at end of the night.
Stars-C2	Stars-C2: Stars do not move but student explains this with the earth's rotation
Stars-D2	Stars-D2: Gives inaccurate description of stars' motion; explains by using the earth's orbit around the sun.
Stars-E1	Stars-E1: Accurately describes stars' apparent motion but uses stars' actual motion to explain this.
Stars-E2	Stars-E2: Gives inaccurate description of stars' motion; explains by using stars moving around the solar system.
Stars-E3	Stars-E3: Stars don't move or move slightly, slowly; explanation is that the stars don't actually move or only move slowly.