

Instructional support for children developing an ability to move between frames of reference in astronomy: Towards a learning progression in celestial motion

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Abstract

In this study, we describe the process of defining and evaluating two aspects of a learning progression in astronomy. These aspects of the learning progression, or *construct maps* (Wilson, 2005), describe how students may develop increasing sophistication towards common topics of elementary astronomy: daily celestial motion and the phases of the moon. Further, we used this analysis as an opportunity to examine the role of different instructional conditions, including traditional instruction, a planetarium program, and a curriculum that focused both on apparent celestial motion and explaining that motion using kinesthetic and hands-on modeling opportunities. Pre/post-instructional interviews were conducted with third grade students who participated in four instructional conditions (N=99) across 11 different classrooms. The results were analyzed using a Rasch modeling approach, allowing us to interpret levels of difficulty among the concepts of celestial motion and phases of the moon. These results were used to define levels of sophistication in the learning progression. Findings support the hypothesis that students need to be supported in learning both the apparent and actual motions; however, the full understanding of daily celestial motion and lunar phases proved to be challenging for the students as few reached the most sophisticated levels of the construct maps in any of the instructional conditions.

Key words: astronomy; learning progressions; elementary; kinesthetic learning; planetarium

Introduction

The study presented here is part of a larger project developing a learning progression for celestial motion (Plummer, 2011). In particular, this line of research examines how children from elementary through middle school can develop improved sophistication in moving from an earth-based perspective on their astronomical observations to explaining those observations with the actual motions and orientations of objects in the solar system and beyond. Such work is needed to help students learn in ways that develop coherent expertise in understanding the connections between various phenomena associated with astronomy at the K-8 level. Research framed in a learning progression framework provides a structure for examining these issues and producing results that can be used to inform improvement in curriculum, assessment, and policy.

The goal of this study is to investigate two pieces of the larger learning progression by considering the role of instruction in moving third grade students along the learning progression. We investigated the relationship between students' understanding of the earth-based and heliocentric patterns in order to describe potential pathways towards the scientific conception of daily celestial motion and the phases of the moon. Daily celestial motion refers to the apparent pattern of observable rising and setting of the sun, moon, and stars, as a result of the actual motion of the earth rotating every 24 hours. The changing appearance of the moon over the course of the month can be explained by the relative orientation of the sun, earth, and moon resulting in different amounts of light observable on the moon's surface from the earth, as the moon slowly orbits the earth. These are complex areas of reasoning that require children understand and imagine two complex sequences of motion through an understanding of different *frames of reference*. First, they must visualize the apparent motions of these objects, from their own perspective. Second, they must also imagine a new space-based perspective from which to explain why celestial objects appear the way that they do as seen from the earth. These shifts rely on children imagining concepts that change over time and at different timescales (days, months, and years). This type of reasoning between moving frames of reference is necessary for other topics of K-12 astronomy such as eclipses, tides, planetary motion, and the seasons.

Without targeted instruction, research suggests that most children will not develop the robust ability required to describe both the earth-based and heliocentric reference frames in daily celestial motion nor to construct the scientific explanation for lunar phases. Limited research has addressed the combination of children's ability to describe apparent daily celestial motion and their explanations from a heliocentric perspective. However, research on children's mental models regarding the day-night cycle may begin to shed light on the nature of their understanding of daily celestial motion from a frames of reference perspective. Children's early explanations for the day-night cycle are primarily based on two general presuppositions: the Sun (and sometimes Moon) is blocked resulting in night time darkness and that the Sun moves straight up and straight down (Samarapungavan, Vosniadou, & Brewer, 1996; Vosniadou & Brewer, 1994). Studies using elementary-aged children's drawings and physical models have found a progression moving towards more heliocentric explanations for the day-night cycle; understanding the scientific explanation first requires students understand the spherical shape of the Earth (Samarapungavan et al., 1996; Vosniadou & Brewer, 1994). The progression of

children's explanations towards the scientific includes several levels of synthetic mental models which combine aspects of the naïve with aspects of the scientific, such as day and night are caused by the Earth revolving about the Sun (Vosniadou & Brewer, 1994).

Several studies have also investigated the range of difficulties that students have in understanding the phases of the moon. Kavanagh, Agan, and Sneider reviewed 12 studies from elementary through preservice teachers which focused on uncovering alternative ideas about the lunar phases. In early elementary school, students often believe that the clouds or "darkness" cause the phases. Older children through adulthood favor the alternative mechanism of "blocking" in which the earth blocks light from reaching the moon. Several studies have also examined the role of various instructional approaches in improving understanding of the lunar phases. Prior research suggests that students will need to engage in some form of interactive modelling to reach the scientific level of understanding of lunar phases (Barnett & Moran, 2002; Kavanagh, Agan, & Sneider, 2005; Trundle et al., 2010).

Many adults also do not hold a scientific understanding of these topics. Surveys with large numbers of preservice and practicing teachers suggest that most do not hold the scientific conception for many sun-earth-moon concepts (Brunsell & Marcks, 2005; Schoon, 1995; Trumper, 2001, 2003, 2006). Mant and Summers (1993) concluded that the English elementary teachers in their interview study did not have a good observational foundation and were instead working from non-normative mental models to construct inaccurate descriptions of the apparent motion of the sun, moon, and stars. A large fraction of both American and English practicing and preservice teachers hold alternative ideas about the explanation for why we have day and night, such as the sun moving around the earth (Atwood & Atwood 1995; Mant & Summers 1993; Parker & Heywood 1998). Many American preservice teachers also hold alternative ideas about the phases of the moon (Abell, Martini, & George, 2001; Trundle et al. 2002, 2006). In a study of preservice elementary teachers in a science methods course, participants who conducted open-inquiry investigations of celestial motion topics did improve their understanding of astronomy, but the impact was limited – students needed more guidance in developing a rich understanding of these topics and continued to exhibit non-normative ideas and explanations (Plummer, Zahm, & Rice, 2010).

The present study follows on the first author's previous work in understanding the role of instruction in improving daily celestial motion knowledge among children. Plummer's previous research uncovered the range of ways elementary-aged children describe the pattern of apparent celestial motion as well as a successful method of instruction: a kinesthetic planetarium program (2009a, 2009b). However, these studies did not examine how children learn to explain these patterns in a way that clearly examines each perspective (the Earth-based and heliocentric frames of reference). Therefore, the first and third authors collaborated to test an instructional approach that combined instruction that engaged students in learning to describe apparent motion with using kinesthetic and hands-on modeling to explain those motions (Plummer, Wasko, & Slagle, 2011). We examined the results of two days of instruction with a group of third grade students in a gifted and talented program (N=16). While most students improved, and many reached the scientific level of explanation for daily celestial motion, a few challenges appear to hinder the remaining students from moving to more sophisticated levels of understanding. Students

exhibited difficulties in the interplay between the relatively quick rotation of the Earth and the much slower orbit of the Moon with respect to explaining the Moon's apparent motion even after instruction. This concept is more complex as it requires integrating the implications of two moving objects (the earth and moon) with a single resulting motion in the earth-based frame of reference. A second challenge appeared in the resistance towards using the Earth's rotation to explain that the stars' apparent motion. Students were explicitly taught these frames of reference through visual observation and kinesthetic modeling; however, a number of students considered to express non-normative ideas on the stars' apparent motion. Some of this may be due to their limited knowledge of the distance to the stars as well as the overall complexity of imagining thousands of stars appearing to rise and set (compared to the relatively simple ability to imagine a single sun or moon rising and setting). These changes in understanding may require a more radical change in the students' conceptual framework rather than a more general additive growth (Vosniadou, 2007).

This previous study provides the basis for the instructional intervention examined here and some of the "lessons learned" were used to further develop appropriate contexts and experiences for the students in this study. We wondered how those instructional strategies would translate into a traditional third-grade classroom taught by typical elementary teachers (instruction in the previous study was taught by the first and third author) and will discuss how these were implemented as part of a larger 6-week curriculum later in this paper. Further, we wished to use this intervention to provide empirical evidence for the levels of sophistication within the learning progression.

Theoretical Framework

Learning progressions

Learning progression research has the potential to provide needed coherence and direction for science education. In general, astronomy education receives a small allotment of instructional time (Plummer & Zahm, 2010). Yet current instruction in astronomy, like other areas of science, is likely to be characterized as fragmented, focused on breadth rather than depth, and emphasizing inconsequential facts rather than the core of the discipline (Kesidou & Roseman, 2002). This suggests that teachers, through their use of fragmented curriculum, may not be taking full advantage of the short amount of time allocated to astronomy content. In addition, the current research base lacks coherence across conceptual topics and has a limited coverage of instructional interventions (Bailey & Slater, 2003; Lelliott & Rollnick, 2010) – work that is needed to move the field forward in ways that can help teachers, as well as curriculum and assessment developers. Further, while national policy documents recommend that students become proficient in science in ways that go beyond basic facts and explanations of phenomena (NRC, 2007), how to successfully support children in developing an integrated view of astronomy and the nature of science remains an open question.

One goal of learning progression research is to support the development of research-based standards and curricula that focus on big ideas of science in ways that help students see the major themes and concepts tying phenomena together (Corcoran, Mosher, & Rogat, 2009). Such an emphasis is reflected

in the recent work to develop new national science standards: Framework for Science Education (NRC, 2010). Learning progression research also provides an opportunity to improve the coherence of science curricula from the time students enter school through graduation, and beyond; researchers have begun to examine how learning progression research can be used to investigate curriculum design (Krajcik, Shin, Stevens, & Short, 2009; Wiser, Smith, Doubler, & Asbell-Clark, 2009) and teacher training (Schneider & Plasman, 2011). Though the field is still negotiating the details of what it means to design, revise, and validate a learning progression in science, there are several commonalities in the approaches taken by researchers who work in this area. Learning progressions describe how learners may grow in sophistication towards a big idea in science (Corcoran, Mosher, & Rogat, 2009; Duncan & Hmelo-Silver, 2009; NRC, 2007). These big ideas describe unifying concepts that help make sense of a broad variety of phenomena, offering robust explanatory power for the world around us (Smith, Wiser, Anderson, & Krajcik, 2006). A learning progression describes how intermediate levels of sophistication can be valued and built upon, rather than only focusing on alternative ideas and scientific ideas. As part of valuing increased sophistication through intermediate levels of understanding, learning progression research focuses on the role instruction plays in moving students from the knowledge they students bring with them to school towards the scientific conception. Further, most learning progressions describe how understanding is developed across many grades, though breadth of the progression and the grain-size of analysis vary between research groups and topics (Heritage, 2008).

Celestial motion was chosen as a big idea to develop into a learning progression based on three criteria (Plummer, 2011):

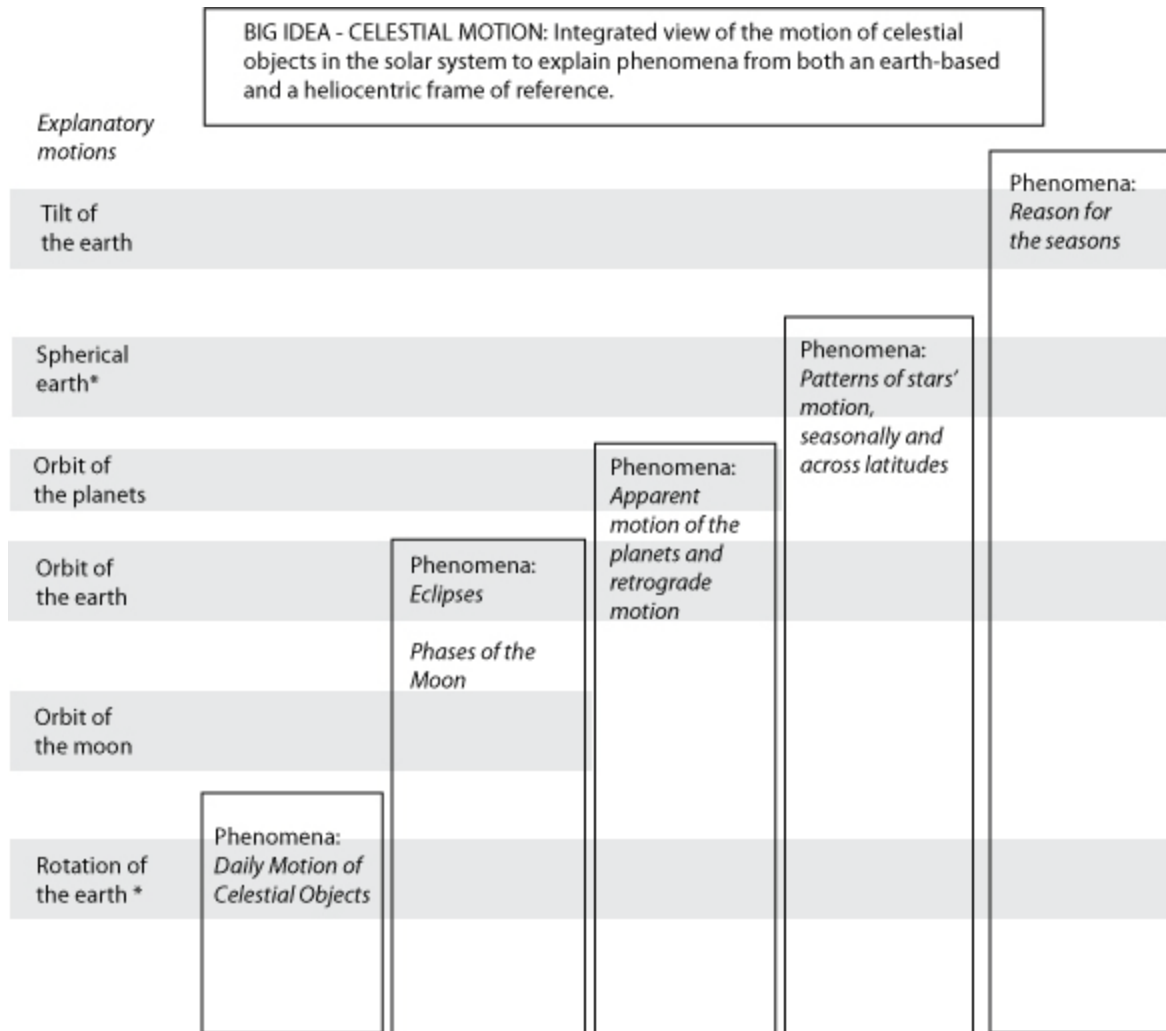
1. Big ideas are those that are important to the field of astronomy. Astronomy, as a science, is concerned with describing and explaining the universe as a whole. Thus big ideas in astronomy are those that represent ways of knowing and understanding the universe.
2. Big ideas describe explanatory models that can be learned by beginning with a child's observations of the world. This begins to capture the "increasing in sophistication" criterion generally accepted in the definition of learning progressions (Corcoran, Mosher, & Rogat, 2009; NRC, 2007; Smith et al., 2006).
3. Big ideas can explain multiple, unified astronomical phenomena such that learning to explain an individual phenomenon helps the learner build in sophistication towards the big idea and, thus, explanations of additional phenomena.

The big idea of celestial motion can be described as a response to the question: How do we explain our earth-based perspectives of astronomical phenomena using the actual motions and properties of celestial objects? Astronomical phenomena observed from an earth-based perspective (such as the patterns of apparent daily motion of celestial objects, seasonal changes, and the phases of the moon) can be explained using the earth's rotation and tilt, the earth's orbit around the sun, and the moon's orbit around the earth (Plummer & Krajcik, 2010).

Ultimately, the big idea of celestial motion combines two concepts: motions of celestial objects and the observer moving between frames of reference to understand observable phenomena. The various phenomena explained by this big idea are not caused by the same underlying motions; however, explanations of these phenomena are unified by reliance upon the motion of celestial objects.

Given the nature of the celestial motion big idea, a possible solution for addressing these complexities is to use Wilson's (2009) proposal to build learning progressions from sets of construct maps. Each construct map has a separate astronomical phenomenon as the top anchor, which could allow us to focus on a single set of earth-based observations and their associated explanatory motions (e.g. daily apparent celestial motion and the rotation of the earth). Construct maps can be stacked or aligned to create a full learning progression leading towards a single big idea which students may reach with appropriate instruction. Figure 1 shows potential construct maps connected within a single learning progression for celestial motion; earth-based observable phenomena and associated explanations in the heliocentric frame of reference are used to link the concept maps together. The explanatory motions for each phenomenon (descriptions of what is actually happening in the solar system) appear along the left hand side. Some of these explanatory motions of celestial objects are used to explain multiple phenomena (and, thus link to multiple construct maps), such as rotation of the earth and orbit of the earth. This type of connection is indicated by the grey shaded bands in Figure 1. This is just a rough sketch of the layout of the construct maps, not a completely articulation; this representation does not show the intermediate levels or all of the necessary links between the construct maps.

In this representation (Figure 1), learning progresses upward through levels of increasing sophistication; lower levels of each construct map representing naïve ways of knowing as students enter school. Higher levels of each construct map represent increasingly sophisticated understanding of how to use the actual motions of celestial objects to provide aspects of the scientific explanation for an earth-based observable phenomenon. A full and rich understanding of celestial motion occurs as students explore connections between the different construct maps so that they see celestial motion as not just a collection of phenomena but as part of a larger pattern of motions.



* Students need to understand that the earth is a sphere before learning to explain with the earth's rotation. Later, students will interpret the consequences for our observations of the sky using the shape of the earth and their location on that sphere.

Figure 1. An outline of how earth-based phenomena and the actual heliocentric motions within the solar system can be linked within a learning progression for celestial motion. Each of the five vertical columns is a construct map. The grey shaded bands indicate where explanatory motions (left column) link to each of the construct maps. For example, the grey band representing the rotation of the earth overlaps all of the construct maps because it is part of the explanation for all of the phenomena. Figure from Plummer (2011).

Methodology

Interpretations of students' pre-instructional understanding and the design of the specific learning environment were based on the framework theory approach to conceptual change. In this theoretical framework, conceptual change can occur both through a radical restructuring which involves ontological category shifts as well as through gradual assimilation of new concepts within the existing mental framework (Vosniadou, 2007). At the heart of this theoretical approach "is the idea that initial

explanations of the physical world in naive physics are not fragmented observations but form a coherent whole, a framework theory” (Vosniadou, Vamvakoussi, & Skopeliti, 2008, p. 4). A learner’s experience in the classroom and other cultural experiences may result in the assimilation of ideas that, rather than replacing the naive theory, form synthetic models which include aspects of the scientific view with the personal, naive theory (Vosniadou & Brewer, 1992). Several empirical studies support the usefulness of the framework theory towards describing how children learn about the natural world (e.g. Blown & Bryce, 2010; Ioannides & Vosniadou, 2002; Vosniadou & Brewer, 1992, 1994).

Instruction

The students were drawn from elementary schools across a suburban school district in the Eastern US. Each elementary school serves between about 350-450 students in grade K-3. Almost all students in this study had visited the district planetarium during the previous school year but had otherwise not received extensive classroom instruction in astronomy prior to the study. Based on the school district’s website, the student body demographics includes: 81.5% White, 2.1% Hispanic, 8.5% Black, 4.8% Asian/Pacific Islander, and 3% Multi-racial American students.

To investigate the role that instruction plays in children developing the ability to accurately describe and explain their earth-based observations of daily celestial motion, we investigated the learning outcomes of children in four instructional conditions:

Condition 1 – Traditional Instruction: Students in this condition participated in their school district’s traditional third-grade astronomy curriculum. A sample of students from four classrooms were interviewed before and after instruction (N=24). The results of the pre-instructional interviews were previously reported in Plummer, Wasko, and Slagle (2011). The teachers had been teaching this particular curriculum with third grade students between 2-4 years and each had additional experience as elementary teachers in other grade levels. The district astronomy curriculum includes approximately 6 weeks of lessons (19 lessons total). The major concepts included in this unit include: the rotational/revolutionary relationships among the sun, earth, and moon, the sun illuminating the moon, explanation of the phases of the moon, characteristics of the moon’s surface, and the history of space travel. The concepts relevant to this portion of the celestial motion learning progression appear in *Defining Rotation and Revolution* (2 days), *Explaining the Phases of the Moon* (3 days), and *Eclipses* (1 day). In *Defining*, 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. Students 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 *Phases*, students are asked to make a prediction of the cycle of the phases of the moon and make observations of the moon over a month. The explanation for the phases of the moon is modeled using a lamp and a Styrofoam ball. In *Eclipses*, 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.

Two of the four teachers were interviewed to extend our understanding of how the curriculum is enacted. These two interviews were representative of the four teachers because these teachers followed the same curriculum and worked together closely in the same school for multiple years (the other two teachers were not available to be interviewed). The teachers recognize the value of using kinesthetic-based instruction for celestial motion. Students physically rotated to explain the day/night cycle and to define the key vocabulary words. Teachers briefly discussed the sun's rising and setting but did not spend extended time focusing on the connection between the earth's rotation and the apparent motion. As expected, based on the curriculum and research on teachers' beliefs (Shen & Confrey, 2010), the teachers primarily focused on the actual motion of the celestial objects. The kinesthetic strategies were used more to demonstrate concepts rather than to make connections across the conceptual domain. In the remaining instruction, students often observed the teachers model the phenomena, such as using a flashlight and ball to demonstrate the phases or demonstrating the sun-earth-moon system motions using an orrey. Teachers left instruction relating to the stars to the planetarium (students visit once or twice a year); planetarium instruction is not included in the time frame of this curriculum enactment. Thus the primary focus for the relevant lessons of this unit are the actual motions of the earth and moon in the solar system without making a direct effort to help students move between frames of reference to explain earth-based patterns of motion (aside from the phases of the moon, which was taught through demonstration rather than student-centered strategies).

Condition 2 – the kinesthetic planetarium program: Two third grade classes visited the District's planetarium (in separate visits); a sample of students were interviewed from each classroom, before and after instruction (N=22). This 45-minute live planetarium program was taught by the district planetarium director (third author of this paper). The program engaged students kinesthetically with apparent celestial motion by asking the students to use their arms to trace out the motions of the sun, moon, and stars as they appear to rise and set. The program also briefly addresses the idea that we see different phases of the moon on different nights. A version of this program has previously been shown to increase first and second grade students' knowledge of apparent celestial motion (Plummer, 2009b). Students in this condition did not receive additional instruction on astronomy during the time between the planetarium program and the post-instruction interview (about a week later).

Condition 3 – revised classroom instruction: To investigate the importance of classroom instruction designed to support students learning both the observations and exploring models to construct explanations, a group of eight third-grade teachers participated in professional development around these topics. Two of these teachers agreed to be part of Condition 3 by teaching new lessons and revising their existing instruction. A sample of their students were interviewed before and after instruction (N=21). The professional development (PD) consisted of three 2-hour workshops in the district planetarium (though only 2 of these workshops are relevant to this study; the third related to the reason for the seasons). The purpose of the PD was to introduce the teachers to lessons which would replace or enhance existing aspects of their astronomy curriculum (size and scale, daily celestial motion, phases of the moon and seasons). In total, about six days of instruction were changed or enhanced, based on the professional development. The teachers participated in new or revised activities while the facilitators (the first and third authors) discussed the purpose of the new activities

and how they would support student learning. Many of the new lessons were based on our previous experience conducting a small instructional intervention in a program for third grade gifted students (Plummer, Wasko, & Slagle, 2011). We were initially concerned that the brevity of the PD would limit the extent to which teachers changed their beliefs and practices. However, the PD model used here both represents aspects of common practice in the field (short in-service opportunities) and draws on lessons learned about appropriate PD practices (tied into the actual teacher practice by focusing on concepts that they would be teaching that year). The instruction was designed to emphasize both the earth-based observations and the explanations for those observations through kinesthetic and hands-on modeling activities.

Condition 4 – included both the planetarium program and the revised classroom instruction: Three teachers who attended the PD also took their students to the planetarium during the instructional period for the unit and taught the revised version of the curriculum (N=32). However, because of scheduling issues, the students visited the planetarium in early December but did not start the unit until later in December, followed by the winter break, leaving some or most of the unit to January. Thus the planetarium program was not integrated in the way in which we hoped this interaction would occur.

The purpose of examining four different conditions is not because we think that the importance of combining observational and modeling strategies is under question, but to explore the extent to which each of these strategies can help facilitate learning as well as uncover areas that continue to be challenging to elementary students even after targeted instruction.

Interviews and coding

Interviews, lasting about 15 minutes, were conducted before and after instruction using generative questions to tap into students' mental models rather than only factual recall (Vosniadou & Brewer, 1994). First, students described their understanding of apparent celestial motion using a flashlight in a small planetarium-like dome. Second, students explained their demonstrations using physical models of the sun, earth and moon. Variations on these interview protocols have been used in previous studies (Plummer, 2009a, 2009b; Plummer, Zahm, & Rice, 2010; Plummer, Wasko, & Slagle, 2011). 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.) resulting in the primary categories (Plummer, Wasko, & Slagle, 2011). The first and second authors individually coded a sample of 34 interviews (inter-rater agreement of 92.9%).

A set of three categories were created to classify students' use of explanations for the sun, moon, and stars' apparent motion. Each secondary category includes a series of codes defined by combining the primary codes for apparent and actual celestial motion. An additional secondary code was developed to understand the influence of instruction on the children's overall understanding of apparent celestial motion by creating a Guttman scale (Wilson, 2005) using the primary codes. At the most naïve level, students cannot describe the sun, moon, or stars as appearing to rise and set. At the scientific level is the notion that the sun, moon, and stars appear to rise and set in smooth paths from east to west.

In the final stage of coding, we combined the secondary codes to create the tertiary codes which represent each student's overall understanding of daily celestial motion. Numerical ranking is based on the underlying sophistication of their explanatory model and begins with ordering the accuracy of possible relationships between the explanation for the sun's apparent motion and the description of that apparent motion. The final ranking of these tertiary codes was determined by the Rasch modeling analysis described below. The primary, secondary, and tertiary categories and codes are included in Appendix A.

Analysis methods

Given the ordinal nature of the data, non-parametric tests were used to look for differences between and improvement in understanding from the instructional conditions (Cronk, 2008). First, the Kruskal-Wallis H test was used to determine if the four conditions' students were drawn from the same population and then to determine whether one had made greater progress in understanding celestial motion. To determine improvement within a condition, the Wilcoxon signed ranks test was employed. To determine difference across outcomes, the Mann-Whitney test was used for those categories where we previously found a significant difference across the four conditions using the Kruskal-Wallis H test on the post-instructional results.

The software *ConstructMap* (Kennedy, Wilson, Draney, & Tutunciyar, 2007) was used to perform item response modeling to describe students' proficiency levels in relation to the difficulty of items. In this case, the *items* were 20 categories generated by our coding of the interviews (this included 16 primary codes and 4 secondary codes listed in Appendix A). Initially, all 21 primary codes were included in the analysis, but five of these codes had poor infit values and were therefore dropped from the analysis. Those categories were: *SunPath*, *MoonOpp*, *MoonPath*, *StarsOpp*, and *StarsApp*. *ConstructMap* produces Wright Maps which were used to determine relative difficulties of items on our assessment and to compare person estimates against the levels of difficulty. Note that *ConstructMap* treats each student's pre-instruction and post-instruction outcomes as separate "persons" in the analysis.

We used this analysis to determine the ordering of levels on the daily celestial motion (DCM) construct map (by further sorting and ranking the tertiary codes in Appendix A) and finding the relative difficulty of the levels of the lunar phases construct map with respect to the DCM levels. First, the relative difficulties of items were used to create a potential order of concepts. Levels of the construct maps were ordered in response to difficulty of concepts according to the interview outcomes. Second, the person estimate distributions on the Wright Map were analyzed for both pre-instruction and post-instruction to estimate how the instruction moved students along the proposed empirical-based learning progression.

Findings

The findings are presented here in three parts. First, we discuss the results of the Rasch modeling analysis and how that influenced the design of the daily celestial motion and lunar phases construct maps. We then use the construct map outcomes to categorize the students into levels along these parts of the learning progression to begin to suggest ways in which the learning progression can be a tool to

interpret student learning. Second, we look for where students improved in their understanding by comparing pre to post-instruction interviews for each condition. Finally, we present a more detailed statistical comparison of the four instruction conditions to highlight the differences in outcomes to understand the role of the different learning opportunities presented to the children.

Part 1: Building and Evaluating the Construct Maps

Figure 2, below, shows the Wright Map produced by *ConstructMap* using all students' pre- and post-instructional results for 20 categories (items). The number after the decimal place indicates the level within that item. For example, item #20 was a four-level secondary category. The highest level of sophistication for that category (the idea that the sun, moon, and stars all rise in the east and set in the west) is represented by 20.3 on the Wright Map. The X next to 20.3 represents a student with a 50% probability of having that level of knowledge (i.e. getting that item "right"). That student has a much higher probability of achieving the lower levels of that item, such as 20.2 which means that the student would know that at least two celestial objects rise and set while the third appears to move continuously (such as describing the stars' apparent motion). We have labeled some of the most important item levels in Figure 2 but the names for all 20 can be found in Appendix A.

Below, we will present how this Wright Map can be used to support the levels of sophistication on the DCM and Lunar Phases construct maps. But first, we point out some interesting features of the Wright Map based on the item difficulty.

Concepts that were relatively easy for these third grade students: Some items appeared at or near the bottom of the Wright Map, indicating the "easiness" of these concepts. The shape of the earth and knowledge that the moon appears differently in the sky at different times (drawing 2 or more accurate pictures of the lunar phases) were concepts that nearly all students knew before instruction. Other relatively easy concepts were that the stars are still in the sky during the day (#2.1), and that the moon takes more than a single night to change its appearance significantly (#8.1), and that the earth rotates but without regard for the accurate length of time for this motion (#9.1).

Concepts that were relatively difficult: Concepts that required more complex coordination between moving frames of reference were the most difficult items for the students. These were the items that required students to both have an accurate description of some aspect of apparent motion and then explain that with the motions of celestial objects. The two most difficult of these related to the moon: the lunar phases and the reason why the moon appears to rise and set. In particular, item #18 is interesting because the upper most level requires that a) students describe the moon as rising and setting across the sky, b) explain this using ONLY the earth's rotation and c) also describe the moon's orbit as taking about a month but not include this motion as part of the explanation or the 24-hour cycle of rising and setting.

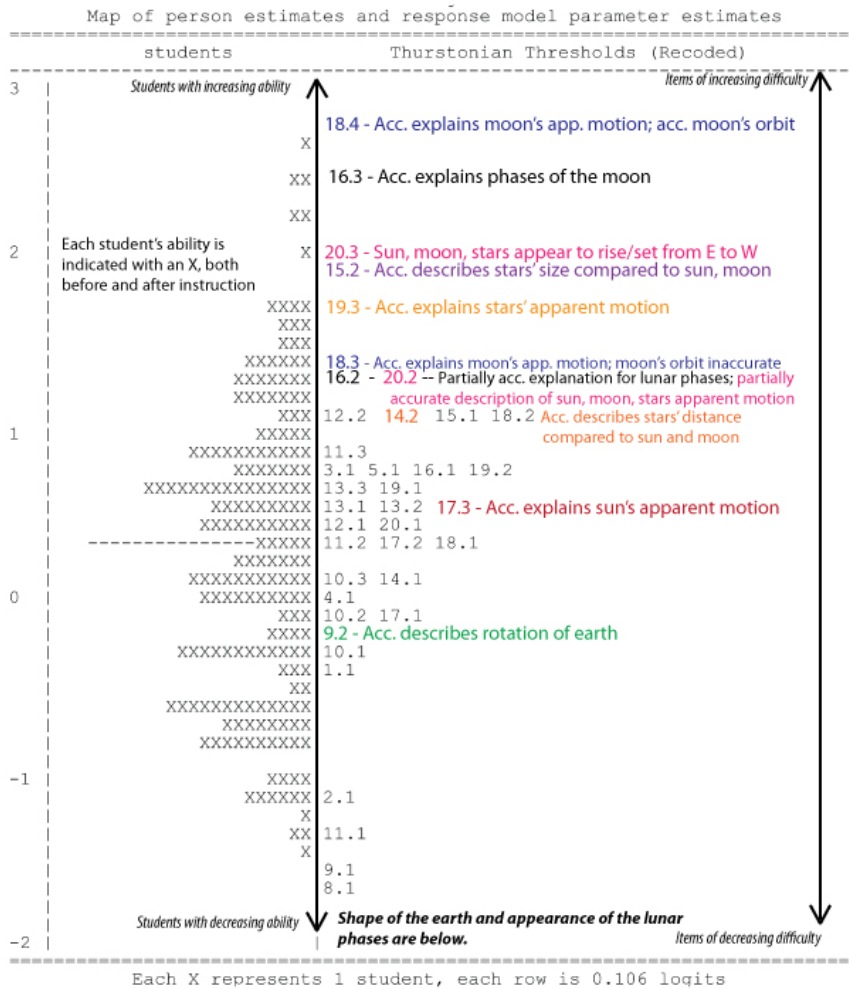


Figure 2. The Wright Map above shows primary and secondary codes (on the right) and students relative abilities with respect to the items, on the left. Items increase in difficulty while students increase in ability as you move towards the top of the figure. Items of particular interest for the construct maps are labeled.

Knowledge and use of the earth's rotation and the day-night cycle: The ability to accurately demonstrate the earth's rotation and knowledge that this takes 24-hours is a relatively easy concept for the third graders (item #9.2). Item #10 describes four potential levels for the use of the earth's rotation in explaining why the sun appears to move. The highest level (#10.3) is the use of an accurate description of the earth's rotation to explain this phenomenon. Level 3 (#10.2) uses the earth's rotation non-normatively or combines it with the earth's orbit in the explanation. Level 2 (#10.1) combines the earth's motion with the sun also moving as the explanation. Below that level, students only used the sun's actual motion to explain their observations. We note that these levels are rather tightly clustered around the accurate knowledge of the earth's rotation. In other words, there is very little increase in

difficulty between having some limited knowledge that the sun's apparent motion could be caused by some other actual motion of the earth to an accurate explanation using the earth's rotation. Also note that just below these items, making this only slightly easier, is #1.1 – the idea that the sun appears to move across the sky in a smooth path (as opposed to rising straight up and down, or other non-normative paths).

Item #17 is the secondary category that combines both how students describe the apparent motion and how they explain that motion. Levels #3 and #4 (17.2 and 17.3, respectively) have accurate descriptions of the sun's apparent motion; 17.3 explains that accurate apparent motion with an accurate use of the earth's rotation while 17.2 has inaccurate use of the earth's rotation to explain an accurate apparent motion of the sun. These levels are more difficult, demonstrating the difficulty in moving between these frames of reference accurately by comparing how the earth's actual motion produces the apparent patterns of motion that we observe.

Analyzing the Wright Map lead to the creating of the two construct maps in Figure 4: The levels indicated for the Phases of the Moon are aligned to the levels on the Daily Celestial Motion construct map in their relative position of difficulty of achieving those levels. Based on these levels, a series of tertiary codes were developed which describe an individual child's overall mental model of daily celestial motion. Each code that combines the four *secondary codes* as broadly defined by the DCM construct map. These codes can be found in Appendix B.

Student Outcomes along the Construct Maps: Table 1 presents the frequency of students assigned to each of the levels of the construct map for daily celestial motion. An analysis using the learning progression as a tool for describing change allows us to begin to unpack what it means to learn about celestial motion in elementary school. First, prior to instruction, most children had a naïve perspective about DCM: they explained any apparent motion or lack of motion with the objects themselves actually moving. The next most frequently ascribed mental model is the synthetic level in which non-normative descriptions of the earth's motion are used to explain the sun's apparent motion. And while in all of the four conditions we see a shift in the frequencies towards higher levels along the construct map, there are still a limited number of students at the *scientific level*. In the next section we will examine these differences looking for statistical significance.

Daily Celestial Motion

Complete

Sub-level 1: Accurately explains apparent motion of sun, moon, and stars with earth's rotation and describes their apparent motion accurately and in the same direction.

Differentiates between moon's orbit and apparent motion accurately.

Sub-level 2: Same accurate apparent and explanation with earth's rotation.

Doesn't use moon's orbit in explanations of moon's apparent motion but orbit may not be accurate.

Scientific Sun Plus Moon OR Stars

Accurately describes and explains apparent motion of sun with earth's rotation.

May or may not use moon's orbit in explanation of moon's apparent motion.

Explaining stars with earth's rotation is more difficult than for the moon but may be learned in either order.

Scientific sun

Accurately describes and explains apparent motion of sun with earth's rotation but not the moon or stars.

Synthetic

Uses earth's motion in explanation for the sun's apparent motion. Explanation does not accurately use earth's rotation.

Naive

Objects appear to move because of their actual motion. Description of apparent motion likely to be non-normative.

Lunar Phases

Scientific explanation for the phases of the moon - able to demonstrate that the moon's phases change as the moon orbits the earth over about a month. Indicates correct alignments of the sun, earth, and moon for various phases.

Incomplete explanation for the phases of the moon. No alternative conceptions.

Moon's orbit is about a month

Includes both aspects of the accurate explanation and alternative conceptions about the phases of the moon.

Knows and can draw some of the shapes of the moon's phases.
Knows that the change is a slow process and does not occur in one night.

Figure 3. The construct maps for daily celestial motion and phases of the moon. Levels on the phases construct map are displayed next to levels on the daily celestial motion construct map of relative difficulty.

Table 1. Each student in each condition was assigned a level in the celestial motion construct map, based on the levels described in Figure 3.

	Traditional (N=24)		Planetarium Only (N=22)		Revised Classroom (N=21)		Revised Classroom Plus Planetarium (N=32)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Complete Scientific								
Sub-Level 1 (accurate orbit of moon)	0%	0.0%	0.0%	4.5%	0.0%	14.3%	3.1%	6.3%
Sub-Level 2 (inaccurate orbit of moon)	0%	0.0%	0.0%	22.7%	4.8%	0.0%	0.0%	0.0%
Scientific Sun Plus Moon OR Stars	8.3%	4.2%	13.6%	4.5%	0.0%	0.0%	15.6%	37.5%
Scientific Sun	4.2%	33.3%	0.0%	13.6%	4.8%	61.9%	15.6%	34.4%
Synthetic								
Sub-Level 1 (Earth moves)	20.8%	45.8%	22.7%	9.1%	42.9%	9.5%	12.5%	21.9%
Sub-Level 2 (Earth and sun both move)	12.5%	4.2%	18.2%	13.6%	0.0%	9.5%	6.3%	0.0%
Naïve	54.2%	12.5%	45.5%	31.8%	47.6%	4.8%	46.9%	0.0%

As expected, the highest frequency of students gave alternative explanations for the phases of the moon, prior to instruction (Table 2). After instruction, the three classroom conditions saw a shift towards the scientific explanation, though again, few reached the fully scientific explanation for the lunar phases. We did not expect to see improvement from the planetarium program as it did not focus on the explanation for the lunar phases.

Table 2. Each student in each condition was assigned a level in the lunar phases construct map, based on the levels described in Figure 3.

	Traditional (N=24)		Planetarium Only (N=22)		Revised Classroom (N=21)		Revised Classroom Plus Planetarium (N=32)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Scientific Explanation for Lunar Phases	0.0%	16.7%	0.0%	0.0%	0.0%	33.3%	0.0%	3.1%
Incomplete Explanation for Lunar Phases	0.0%	37.5%	13.6%	4.5%	4.8%	19.0%	9.4%	31.3%
Aspects of accurate plus misconceptions	4.2%	12.5%	4.5%	36.4%	4.8%	23.8%	12.5%	25.0%
Alternative explanations for lunar phases	79.2%	29.2%	63.6%	50.0%	76.2%	23.8%	59.4%	40.6%
<i>Unknown (student was not asked or answer was unclear</i>	16.7	4.2	18.2%	9.1%	14.3%	0.0%	18.8%	0.0%

Part 2: Improvement within each condition

In the final step of the analysis, we looked to see what aspects of astronomy students learned in each condition by comparing the pre to post-instructional interviews. Then, with the exception of areas in which the groups were significantly different prior to instruction, we compared across the instructional conditions to see whether some forms of instruction were more successful than others. In Table 3, below, we present the results of conducting the Wilcoxon Signed-Ranks test on all 21 primary and 4 secondary categories, as well as the tertiary category which is the level on the DCM construct map (listed under explanatory models), for each of the four instructional conditions.

Apparent celestial motion: We predicted that Condition 1 would not show significant gains in their descriptions of apparent motion while the two conditions that attended the planetarium program on apparent celestial motion (Conditions 2 and 4) would show significant improvement. Condition 3 (revised classroom only) was most interesting in that most aspects of apparent celestial motion showed significant improvement. The classroom instruction was designed to engage the students in learning about the apparent motion of the sun, moon and stars. This appears to have made an impact on those students.

Table 3. Results of the Wilcoxon Signed Ranks test for each of the 26 variables across each condition to compare students' knowledge from before to after instruction.

Variable	Wilcoxon Z-value and significance			
	Condition 1	Condition 2	Condition 3	Condition 4
Apparent Motion				
SunOpp	1.508	3.606***	4.000***	3.873***
SunPath	0.722	3.314**	3.542***	3.666***
MoonOpp	1.000	2.714**	2.656**	2.887**
MoonPath	0.536	2.266*	1.811	2.368*
StarsMove	1.265	3.162**	1.667	2.324*
StarsPath	1.414	2.714**	1.342	2.324*
StarsOpp	0.577	2.333*	2.000*	3.051**
StarsApp	0.541	2.163*	2.070*	2.502*
Direction	0.655	3.258**	2.754**	3.988***
Explanatory Models				
SunExp	3.166**	1.086*	2.754**	3.957***
MoonExp	1.667	1.118	0.842	0.547
StarsExp	0.620	1.800	2.807**	3.624***
SunSecondary	2.914**	1.854	3.440**	4.059***
MoonSecondary	1.047	1.421	2.638**	1.305
StarsSecondary	1.318	2.516*	3.140**	3.589***
Tertiary	2.744**	1.861	3.369**	3.738***
Other aspects of astronomy				
Rotation	1.604	2.440*	1.706	3.624***
Orbit	3.834***	2.251*	4.379***	4.512***
StarsDay	0.577	0.000	2.236*	2.714**
StarsLoc	0.180	0.632	0.000	0.905
EarthShape	0.000	0.000	0.000	0.000
WhereStars	1.316	1.428	2.745**	3.741***
StarSize	1.890	1.134	2.450**	3.410**
Phases of the moon				
MoonShape	0.816	0.577	1.000	1.342
MoonChange	2.236*	0.000	2.828**	1.890
Phases	3.166**	0.486	3.100**	2.874**

p<0.05:*; p<0.01: **; p<0.001: ***; p>0.05: no star

Explanations for the apparent motion: Each condition showed some improvement in how the students explained the sun's apparent motion, even the planetarium condition which did not focus as deeply on the explanation aspect of celestial motion. The improvement in category *SunExp* suggests that their improvement was in their use of the earth's rotation, aside from their description of the sun's apparent motion, since no significant improvement was seen in the category that combines these motions (*SunSecondary*). The program did include having the students practice rotating themselves so, especially for students who already knew that the earth rotates (but did not apply this concept yet), this experience combined with observing the sun rise and set may have been enough to change their idea.

Similarly, even though Condition 1 (Traditional Instruction) did not include instruction that focused on understanding the connection between frames of reference, the earth's rotation in relation to the day/night cycle was discussed, resulting in significant improvement in this area.

The revised classroom conditions showed improvement in how students used the earth's rotation to explain the stars. Improvement in both *StarsExp* and *StarsSecondary* suggests that this improvement included both changes in the number of students using the earth's rotation and in the number of accurate or partially accurate descriptions for the stars' apparent motion accounted for these improvements. Some statistically significant improvement was also observed in the Planetarium group (Condition 2); given that this was in *StarsSecondary* and not *StarsExp*, the improvement was more likely to be from students who developed more sophisticated descriptions of the stars' apparent motion than shifting to using the earth's rotation to explain.

The most surprising result was that only one moon explanation code showed significant improvement: *MoonSecondary* in Condition 3 (revised classroom only). While we did not anticipate seeing improvement in this area from Conditions 1 or 2, it is unclear why more improvement was not observed across the two revised classroom conditions. Later, we will show that there was also no difference in the post-instructional outcomes on these two variables across the conditions.

Other aspects of astronomy: Table 3 also shows areas of significant improvement for other concepts in astronomy that are related to the apparent motion and explanations. Knowledge of the moon's orbit showed significant improvement in all conditions; this was somewhat surprising for the planetarium condition given that it was covered in such a short period of time. Three areas showed improvement only in the two revised classroom instruction conditions: *StarsDay*, *StarsSize*, and *WhereStars*. This indicates that there was improved understanding that the stars are still in the sky during the day (as opposed to a common alternative conception that the stars go to the other side of the earth during the day) and that stars are not all very small and close to the earth. Those last two variables were specifically integrated into the revised curriculum based on the findings of our previous work with children in the third-grade gifted program (Plummer, Wasko, & Slagle, 2011).

Phases of the moon: All three classroom conditions showed significant improvement in understanding of the phases of the moon. However, as we noted previously, few students reached a scientific understanding and remained at a partial or synthetic level of explanation.

Part 3: Comparing instructional conditions

Before comparing improvement across conditions, a Kruskal-Wallis test was conducted to compare the pre-instructional outcomes for all 26 variables. A significant result was found for three variables, indicating a difference in prior knowledge in these three areas. First, there was a significant difference found between the group's knowledge that *the moon appears to move across the sky* ($H(3) = 8.224$, $p < 0.05$), though no difference was found for the more comprehensive variable describing three different levels of knowledge of the moon's path ($H(3) = 2.33$, $p=0.5$). In the simple version of the code (accurate = moon's path is across the sky), the traditional group and revised plus planetarium groups both had higher average rankings than the other two groups. The three level code describing *the stars' apparent*

motion showed significant difference between groups ($H(3) = 8.836, p < 0.05$). The rankings ranged from the control group at the lowest to the revised plus planetarium group at the highest. The final area of significant difference was the *size of the stars* ($H(3) = 9.672, p < 0.05$). The two groups with the revised curriculum were ranked higher than the traditional and planetarium groups.

Next, we looked for statistical differences between the outcomes of the 26 variables to begin to unpack the variations in learning afforded by the different instructional settings. Looking at the results in Table 4 broadly, we see some trends that match our predictions. First, the two conditions that attended the planetarium, in most cases, were significantly more accurate in their descriptions of those apparent motion categories that showed significant difference. However, we note that most of this is in terms of the stars' apparent motion and some limited difference for the sun's apparent motion. This improved knowledge of the stars is likely the reason for the increased improvement in their overall model of the sun, moon, and stars' apparent motion (indicated by the secondary category *direction*).

We also had predicted that the revised curriculum would result in more students learning to use the earth's rotation accurately in their explanations of the apparent motion of the sun, moon, and stars. In general, the data supports this claim. However, the improvement in the revised curriculum over the traditional curriculum was only seen in the explanations for the sun and stars' apparent motion. And while conditions 3 and 4 were significantly improved in their tertiary level code (i.e., their position on the DCM construct map) compared to the traditional curriculum, we were surprised to find that the planetarium condition was not significantly different than any of the classroom instructional groups in their final rankings.

Finally, we find that the revised curriculum was not significantly better than the traditional curriculum in helping the students learn about the phases of the moon. This can be explained: only a very short amount of time was spent on this concept in the professional development and the changes to the curriculum were minor.

Table 4. Results of non-parametric tests for significance between conditions.

Variables	Kruskal-Wallis H score (3 df)	p-value and significance	Which condition ranked higher than the other?	Comparison with Mann-Whitney test	p-value and significance
Apparent motion					
SunOpp	9.991	0.019*	Cond 3 > Cond 1 Cond 4 > Cond 1	190.5 284.0	0.035* 0.006**
StarsMove	24.723	< 0.001***	Cond 2 > Cond 1 Cond 3 > Cond 1 Cond 4 > Cond 1	102.0 159.0 168.0	<0.001*** 0.013* <0.001***
StarsPath	27.571	<0.001***	Cond 2 > Cond 1 Cond 3 > Cond 1 Cond 4 > Cond 1 Cond 2 > Cond 3 Cond 4 > Cond 3	106.0 189.0 140.0 150.5 206.5	<0.001*** 0.039* <0.001*** 0.024* 0.006**

StarsOpp	13.231	0.004**	Cond 4 > Cond 1 Cond 2 > Cond 1	244.0 155.0	0.002** 0.001**
StarsApp	25.037	<0.000***	Cond 2 > Cond 3 Cond 4 > Cond 1 Cond 2 > Cond 1 Cond 4 > Cond 3	136.0 148.0 111.0 188.0	0.011* <0.001*** <0.001*** 0.004**
Direction	13.454	0.004**	Cond 4 > Cond 1 Cond 2 > Cond 1 Cond 4 > Cond 3	188.0 175.0 196.0	0.001** 0.039* 0.008**
Explanation models					
SunExpPost	9.000	0.029*	Cond 4 > Cond 2	228.0	0.007**
StarsExp	19.055	<0.000***	Cond 4 > Cond 2 Cond 3 > Cond 1 Cond 4 > Cond 1	221.5 151.5 161.5	0.007** 0.010* <0.001***
SunSecondary	17.042	0.001**	Cond 3 > Cond 1 Cond 4 > Cond 1 Cond 3 > Cond 2 Cond 4 > Cond 2	167.5 195.5 152.0 196.0	0.033* <0.001*** 0.027* 0.01**
StarsSecondary	18.168	<0.000***	Cond 2 > Cond 1 Cond 3 > Cond 1 Cond 4 > Cond 1	160.0 129.0 150.0	0.015* 0.002** <0.001***
Tertiary	13.451	0.004**	Cond 3 > Cond 1 Cond 4 > Cond 1	157.5 162.5	0.021* <0.001***
Other categories					
StarsDay	16.591	0.001**	Cond 3 > Cond 2 Cond 4 > Cond 2	147.5 219.0	0.006** 0.001**
WhereStars	10.998	0.012*	Cond 3 > Cond 2 Cond 4 > Cond 2	140.0 201.0	0.018* 0.004*
StarSize	32.291	<0.000***	Cond 3 > Cond 1 Cond 4 > Cond 1 Cond 3 > Cond 2 Cond 4 > Cond 2	95.0 129.0 95.0 132.0	<0.001*** <0.001*** <0.001*** <0.001***
MoonChange	10.158	0.017*	Cond 1 > Cond 2 Cond 3 > Cond 2	207.0 189.0	0.034* 0.043*
Rotation	12.483	0.006**	Cond 4 > Cond 1 Cond 4 > Cond 2 Cond 4 > Cond 3	256.0 240.0 256.0	<0.001*** 0.001** 0.004**
Orbit	31.017	<0.000***	Cond 1 > Cond 2 Cond 3 > Cond 1 Cond 3 > Cond 2 Cond 4 > Cond 2 Cond 3 > Cond 4	144.0 131.0 48.5 120.0 246.0	0.009* 0.001** <0.001*** <0.001*** 0.034*
Phases of the moon					
Phases	12.836	0.005**	Cond 1 > Cond 2 Cond 3 > Cond 2 Cond 3 > Cond 4	121.0 99.50 230.00	0.005** 0.002** 0.045*

p<0.05: *; p<0.01: **; p<0.001: ***; p>0.05: no star

Conclusions

The findings presented here support our hypothesis that students will improve in their understanding of celestial motion when engaged in instruction that supports their ability to visualize celestial motion through observations and hands-on modeling. Instruction that primarily focuses on the actual motions of the earth and moon does not result in the same level of sophistication as a combined focus on explaining the sun, moon and stars' apparent motion. We also find that these conceptual areas (daily celestial motion and lunar phases) continue to present a challenge for many students, even after targeted instruction, as few students reached the scientific level of understanding. Students need additional time with challenging aspects of the concept and teachers may need additional support in assessing students during instruction to better guide student thinking. For example, one area that appeared to limit children's advancement to the scientific level of the daily celestial motion scale was the difficulty in separating the daily rising and setting of the moon (which is caused by the earth's 24-hour rotation) with the moon's much slower monthly orbit. Further analysis of the interviews will be conducted to attempt to tease out why no significant improvement was seen in this conceptual area across the instructional conditions. Our research also suggests that students will need more time in class to express their understanding of the phases of the moon, after experiencing the hands-on and kinesthetic strategies, to reach a durable, long-term, scientific understanding such as through writing and oral presentation (Trundle et al., 2007).

We were somewhat surprised at the level of improvement in apparent celestial motion exhibited by the students who did not attend the planetarium program. The revised instructional condition included strategies to help the students visualize the apparent motions of the sun, moon, and stars (such as using a flashlight to trace out the sun's path and putting stars on the walls to observe as they slowly rotated). The results seem to suggest that experience worked well in the absence of a visit to the planetarium. The planetarium condition also showed significant improvement. Previous research with 1st and 2nd grade students attending a variation on this kinesthetic planetarium program found significant improvement across all aspects of apparent celestial motion (Plummer, 2009b). This study showed similar improvement among a new population (3rd grade students) and was taught by a different instructor (the third author of this paper). In addition, some improvements were found in how students explain apparent motion, specifically in terms of their resulting explanations for the sun and stars' apparent motion.

The analysis of the student interviews yields a pair of useful tools: the DCM and Lunar Phases construct maps. When used to analyze student improvement, we found that all three classroom instructional conditions moved students along the DCM construct map but that the improvement was more significant for the revised curriculum. Similarly, all three showed improvement for the lunar phases construct map. However, the changes to the curriculum were not substantive enough to allow the revised curriculum students to out-perform the traditional curriculum.

A number of limitations must be discussed in relation to the results of this study. First, we were only able to include five teachers in the revised curriculum conditions. This limits our ability to generalize the curricular changes over nuances in particular teachers' implementation of the curriculum. To improve our interpretation of the relation between the instruction and student learning, we conducted pre and post-instructional interviews with the teachers in these conditions as well as interviews with two of the teachers from the traditional group (post-only). We asked the teachers to describe how they taught each of the major concepts. One of our next steps in this study will be to compare those interviews to the student-outcomes presented here to tease out additional explanations for the patterns of improvement. A second limitation is the timing of the curriculum. Students in the revised curriculum conditions started their instruction before the winter break and concluded the instruction after the break. This may have altered the impact of the instruction on their understanding. Further, the three classes in Condition 4 attended the planetarium program weeks before they began the unit, rather than during the unit as we had initially planned. This may have limited the impact of combining the visualizations provided by the planetarium with the explanations discussed in the curriculum. Finally, our overall evaluation of the two construct maps is limited by the fact that few students reached the scientific level in any of the instructional conditions. More research is needed to understand what changes to the curriculum would be needed to support a greater improvement in these challenging concepts.

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DRAFT

Appendix A: Coding Scheme for Interviews

Note: The numbering scheme for those items used in the *ConstructMap* analysis is indicated in the notes section at the right of each category.

ID#:		Rater:	
Interview:	Pre __ Post ____		

APPARENT CELESTIAL MOTION

The Path of the Sun		Level	Notes
1. Sun-Opp: Does the sun rise and set on opposite sides of the sky?	<i>Accurate:</i> A smooth path that rises and set more than 45 degrees apart.	1	Item #1 on the Wright Map
	<i>Partially Accurate:</i> Same as accurate but the motion is not continuous. For example, sun stops for a while or speed changes during one day.	<i>No examples of this were observed</i>	
	<i>Non-normative:</i> Any other type of path, including paths with sharp turns, or that goes straight up and down.	0	
	<i>Unclear</i> – rater is unable to determine if path is acc, pa, or nn	0	

2. **Describe the path of the Sun:** Check off any descriptions that fit the path described by the student. Ignore motions that are not continuous or that change speeds. (.)

	Level	Notes
A. A smooth arc across the sky, not through the zenith (does not have to be from E to W).	2	Dropped from the Wright Map analysis because of fit
B. A smooth arc across the sky, through the zenith (does not have to be from E to W).	2	
C. A path across the sky (not rising and setting close together) that includes a sharp turn in the middle.	1	
D. Rising and setting position within ~45 degrees of each other.	1	
E. Path that includes rising and setting but includes other inaccuracies not included above (but not including inaccuracies in direction unless direction changes from day to day).	0	
F. No resemblance to the actual path.	0	

The Path of the Moon		Level	Notes
3. Moon-Opp: Does the moon rise and set on opposite sides of the sky?	<i>Accurate:</i> A smooth path that rises and set more than 45 degrees apart. Direction is not important. Motion is continuous.	1	Dropped from Construct Map
	<i>Partially accurate:</i> Same as accurate but motion is not	<i>None-exist</i>	

	continuous. Ex. Moon stops for part of the night or speed of moon changes.		analysis because of fit.
	<i>Non-normative</i> : Any other type of path, including paths with sharp turns, or that goes straight up and down.	0	
	<i>Unclear</i>	0	

4. **Describe the path of the Moon:** Check off any descriptions that fit the path described by the student. (Dropped from ConstructMap analysis because of fit.)

A. A smooth arc across the sky, not through the zenith (does not have to be from E to W).	2
B. A smooth arc across the sky, through the zenith (does not have to be from E to W).	2
C. A path across the sky (not rising and setting close together) that includes a sharp turn in the middle.	1
D. Rising and setting position within ~45 degrees of each other.	1
E. Path that includes rising and setting but includes other inaccuracies not included above (but not including inaccuracies in direction).	1
F. Demonstrates moon appearing to move in the sky but does not rise and set	0
G. Moon rises/sets but spends most of the night up at the zenith.	1
H. Moon appears to move, but student does not demonstrate a path.	0
I. Student does not know if the moon moves.	0
J. Moon does not move.	0
K. Unclear	0

Motion of the stars		Response	Justification
5. Stars-Day: Are the stars still in the sky during the daytime?	<i>Accurate</i> : 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.)	1	Item #2 on the Wright Map
	<i>Non-normative</i> : Student indicates that the stars are not in the sky during the day.	0	
	<i>Unclear</i>	0	
6. Stars- Location: Do people in California see the same stars that we do in PA?	<i>Accurate</i> : Student believes that people in California see the same stars that we do in Pennsylvania.	1	Item #3 on the Wright Map
	<i>Non-normative</i> : Student does not believe that people in California see the same stars that we do in Pennsylvania.	0	
	<i>Unclear</i>	0	

Motion of the stars		Response	Notes
7. Stars-Move: Do the stars appear to move?	<i>Accurate</i> : A verbal response of "yes" or description of a path/motion of a star	1	Item #4 on the Wright Map
	<i>Non-normative</i> : A verbal response of "no" or "I don't know"	0	
	<i>Unclear</i>	0	

8. Stars-Path: Do the stars appear to follow a smooth path in a continuous motion?	<i>Accurate:</i> Motion is smooth, in one direction, and continuous. This could include rising and setting, a smooth arc around the sky, or a circular motion.	1	Item #5 on the Wright Map
	<i>Non-normative:</i> 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."	0	
	<i>Unclear</i>	0	
9. Stars-Opp: Do the stars appear to rise and set on opposite sides of the sky?	<i>Accurate:</i> Demonstrates that a star rises and sets on opposite sides of the sky and says that the stars rise and set (if asked).	1	Item dropped from Wright Map analysis because of fit.
	<i>Partially accurate:</i> 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 on opposite sides of sky but answers "no" when asked if stars rise and set	0	
	<i>Non-normative:</i> Stars do not appear to rise and set or they rise/set but not on opposite sides of the sky.	0	
	<i>Unclear</i>	0	

10. Describe the apparent motion of the stars: Check off any descriptions that fit the path described by the student.

	Level	Notes
A. A smooth arc across the sky showing a star rising up and then setting later in the night	2	Item dropped from Construct Map analysis because of fit. A+anything = 1 B+ anything = 1
B. The star appears to move in a continuous motion in one direction (not back and forth or straight up and down) though not rising and setting	1	
C. Stars appear to move, but in a way that is not continuous and smooth (such as back and forth, or many stars in many directions)	0	
D. Student gives conflicting answers, such as first saying that the stars do not ever move but later saying that they do appear to move	0	
E. Stars only appear to move at the end of the night	0	
F. Stars appear to move but student did not demonstrate	0	
G. Stars do not appear to move	0	
H. Unclear/Unknown	0	

THE SHAPE OF THE EARTH and Moon

THE SHAPE OF THE EARTH and MOON		Response	Justification
11. Can you tell me what the shape of the earth is?	<i>Accurate:</i> Round like a ball Student may say ball, sphere, or use some other way to indicate understanding (such as comparing the earth to the shape of the dome or an apple)	1	Item #6 on the Wright Map
	Round like a circle	0	

	Student gives some indication that the earth is flat but also round.		
	Flat Student indicates earth is flat, without also saying it is round or circular (no aspect of scientific answer)	0	
	<i>Unclear or "I don't know"</i>	0	
12. Does the moon have more than one shape?	<i>Accurate:</i> Yes, student draws more than one accurate shape of the moon (The shapes do not have to be perfect. A shape similar to a crescent or an oval-shape for a full are fine.)	1	Item #7 on the Wright Map
	Yes, student draws more than one shape of the moon but some are inaccurate (For example, drawing a half moon by drawing a line horizontally through a crescent)		
	No, the moon only appears in one shape.	0	
	<i>Unclear or "I don't know"</i>	0	
13. How long does it take for the shape of the moon to change?	<i>Accurate:</i> More than a day (Student may say: A few days, a week, a month, a few months, etc.)	1	Item #8 on the Wright Map
	Happens during one day/night (Student may say a few hours or that we will see different shapes during the same night. Some students may say that the length of time depends on the clouds.)	0	
	<i>Unclear or "I don't know."</i>	0	

EXPLANATIONS FOR CELESTIAL MOTION

Use of rotation		Response	Justification
14. Rotation: Does the student accurately describe and/or demonstrate the concept of the rotation of the earth?	<i>Accurate:</i> Student clearly demonstrates that the earth rotates on its axis in a 24 hour period (1 day) (or gives an accurate verbal description that cannot be confused with other concepts) NOTE: Does not have to <i>use</i> rotation to accurately explain anything – just has the concept.	2	Item #9 on the Wright Map
	<i>Partially accurate:</i> length of rotation is inaccurate. NOTE: length of rotation in justification	1	
	<i>Non-normative:</i> Does not include a demonstration or clear explanation of rotation. For example: Does not show rotation; earth rotates back and forth; earth orbits sun but doesn't rotate.	0	
	<i>Unclear</i>		

15. **Describe the explanation for the sun's apparent motion:** Check off any descriptions that fit the explanation.

	Levels	Notes

A. The rotation of the earth	3	Item #10 on the Wright Map <i>Level 2 is all earth-motion explanations</i> A+(C or D) = 2 <i>Level 1 combines earth-motion and sun-motion explanations</i> A+(E, F, or G) = 1 <i>Level 0 are all sun-motion explanations</i>
B. Inaccurate use of the earth's rotation (such as the direction of the earth's rotation changing, but not calling revolution a rotation)	2	
C. The earth revolving around the sun (student may also inaccurately describe this as "rotation")	2	
D. The earth both rotates and revolves on a daily basis	2	
E. The sun revolving around the earth	0	
F. The sun's own motion, other than revolving (such as moving up and down)	0	
G. Unclear/Unknown	0	

EXPLANATIONS FOR THE MOON'S MOTION		Response	
16. Describe the explanation for the moon's apparent motion: Check off <u>all</u> descriptions that fit the explanation.			
A. The rotation of the earth		3	Item #11 on the Wright Map <i>Level 3 are just earth rotation explanations</i> A+E = 3 <i>Level 2 include inaccurate use of earth's rotation or rotation plus other explanations</i> A+ (C,D,F,G,OR H)=2 <i>Level 1 include explanations that only use moon's own motion</i> <i>Level 0 students believe the moon does not appear to move and does not actually move</i>
B. Inaccurate use of earth's rotation (added 6/10/10)		2	
C. The moon orbits around the earth		1	
D. The moon moves up and down		1	
E. The moon is always on the opposite side of earth from the sun		0	
F. The moon does not appear to move and does not actually move		0	
G. The moon does appear to move but does not actually move.		0	
H. Unclear/unknown		0	
17. Orbit: Does the moon orbit the earth about once a month?	<i>Accurate:</i> The moon orbits the moon once a month. Student shows this by demonstration and/or verbal description.	2	Item #12 on the Wright Map
	<i>Partially Accurate:</i> The moon orbits the earth but in less than 27 days or more than a month. Ex: Moon orbits once a day.	1	
	<i>Non-normative:</i> Any other description. Ex. Moon is always opposite side of earth from sun.	0	
	<i>Unclear</i>		

EXPLANATIONS FOR THE STARS' MOTION	Response	
18. Describe the explanation for the stars' apparent motion: Check off <u>all</u> descriptions that fit the explanation.		
A. The rotation of the earth	3	Item #13 on the Wright Map <i>Level 3 uses the earth's rotation Level 2 combines the earth's rotation with other non-normative descriptions of the earth's motion or stars' apparent motion or just uses the earth's orbit (COMBOS) A+(B,D,E,F)=2 Level 1 combines the earth's rotation with the stars actually moving about the solar system A+C=1 Level 0 does not use the earth's motion in an explanation</i>
B. The orbit of the earth around the sun	2	
C. The stars are actually moving around the earth or around the solar system	0	
D. The stars don't move a lot or only move very slowly	0	
E. The stars do not appear to move and do not actually move	0	
F. The stars only move at certain times (such as the end of the night)	0	
G. Unknown or unclear	0	
19. Where are the stars?		
A. Farther away than the sun and moon	2	Item #14 on the Wright Map A+(B,C,D,E,F,G,H,I)=1 B+F=1
B. Some are closer and some are farther than the sun and moon	1	
C. Farther than the moon but closer than the sun	0	
D. Closer than both the sun and moon	0	
E. Same distance as sun and moon.	0	
F. Around the moon	0	
G. Closer than sun OR moon – other is unclear/not asked	0	
H. Same distance as sun OR moon – other is unclear/not asked	0	
I. Unknown/unclear	0	
20. How big are the stars? (Can choose more than one)		
A. Bigger than the sun and moon	2	Item #15 on the Wright Map A+C=2, A+ (D OR E)=1
B. Same size as the sun	1	
C. Smaller than the sun but bigger than the moon	0	
D. Smaller than the moon	0	
E. Very small/tiny/little rocks	0	
F. Smaller than the sun but unknown compared to moon	0	
G. Unknown/unclear	0	
21. Describe the explanation for the phases of the moon: Check off <u>all</u> that apply to this student		
	Level	Notes
A. <i>Accurate</i> – Student includes the following aspects of the explanation of the	3	Item #16 on the

<ul style="list-style-type: none"> - phases of the moon (in their own words and/or demonstrations): - Half of the moon is lit by the sun - As the moon orbits the earth the amount of the lit side changes from our perspective causing us to see different amounts of the moon <p>Does not use earth's shadow or other non-scientific mechanisms in explanation.</p>		Wright Map C+D=1
<i>B. Fragmented</i> – Student includes aspects of the scientific description but not a full scientific explanation. Does not include non-scientific aspects such as shadows, blocking, or clouds.	2	
<i>C. Alternative fragments</i> – Student includes aspects of the scientific explanation for phases of the moon but also includes some non-normative explanation pieces.	1	
<i>D. Shadows or blocking</i> – Student either refers to the earth's shadow or that something is blocking the moon	0	
<i>E. Clouds</i> – clouds cause the phases of the moon	0	
<i>F. Other</i> – other non-normative explanations (e.g. hungry astronauts, explosions, because the moon is tired, etc.)	0	
<i>G. Unclear or unknown</i> – Includes "I don't know"	0	

22. Secondary Sun Codes

Sun-A1-A	Sun-A1-A: Student gives a generally accurate description of sun's motion and explains with the earth's rotation.	3	Item #17 on the Wright Map
Sun-A1-B	Sun-A1-B: Student gives inaccurate description of the sun's rising and setting and uses the earth's rotation to explain this.	1	
			Level 3 combines accurate earth-motion with accurate apparent-motion
Sun-B1-A	Sun-B1-A: Student gives generally accurate description of sun's motion and explains with earth's rotation and the earth revolving around the sun.	2	
Sun-B1-B	Sun-B1-B: Student gives inaccurate description of sun's motion and explains with earth's rotation and the earth revolving around the sun	1	
Sun-B2-A	Sun-B2-A: Student gives generally accurate description of sun's motion but explains with inaccurate description of earth's rotation.	2	
Sun-B2-B	Sun-B2-B: Student gives an inaccurate description of sun's motion and explains with inaccurate description of earth's rotation.	1	Level 2 uses inaccurate explanation that includes a form of earth-rotation (and doesn't include solar motion) with an accurate apparent motion
Sun-B3-A	Sun-B3-A: Student gives generally accurate description of sun's motion and uses both an accurate description of the earth's rotation and one or more inaccurate descriptions.	2	
Sun-B3-B	Sun-B3-B: Student gives inaccurate description of sun's motion and uses both an accurate description of the earth's rotation and one or more inaccurate descriptions.	1	Level 1 – entire explanation based on earth's motion but
Sun-B4-A	Sun-B4-A: Student gives generally accurate description of sun's motion but explains with inaccurate description of earth's rotation and may include other inaccurate explanations (does not include accurate use of rotation OR sun actually moving).	1	
Sun-B4-B	Sun-B4-B: Student gives an inaccurate description of sun's motion and explains with inaccurate description of earth's rotation and may include other inaccurate explanations (does not include accurate use of rotation).	1	

Sun-B5-A	Sun-B5-A: Student gives a generally accurate description of the sun's motion and explains with the earth's revolution around the sun.	1	<i>either path is inaccurate and/or rotation is not part of the explanation</i> <i>Level 0 – includes the sun's actual motion in explanation</i>
Sun-B5-B	Sun-B5-B: Student gives a generally inaccurate description of the sun's motion and explains with the earth's revolution around the sun.	1	
Sun-C1-A	Sun-C1-A: Student gives generally accurate description of sun's motion and explains with earth's rotation and the sun revolves around the earth.	0	
Sun-C1-B	Sun-C1-B: Student gives inaccurate description of sun's motion and explains with earth's rotation and the sun revolves around the earth (or sun moves up/down).	0	
Sun-C2-A	Sun-C2-A: Student gives generally accurate description of sun's motion but explains using the sun going around the earth.	0	
Sun-C2-B	Sun-C2-B: Student gives generally inaccurate description of sun's motion and explains using the sun going around the earth.	0	
Sun-D1-A	Sun-D1-A: Student gives generally accurate description of sun's motion but explains with sun is actually moving up/down.	0	
Sun-D1-B	Sun-D1-B: Student gives inaccurate description of sun's motion and explains with sun is actually moving up/down.	0	
Sun-D2	Sun-D2: Student gives inaccurate description of sun's motion THAT DOES NOT INCLUDE RISING/SETTING and explanation includes the sun's own motion.	0	

23. Secondary Moon Codes

Moon-A1-A	Moon-A1-A: Generally accurate description of the moon's apparent motion and uses the earth's rotation to explain. Moon orbits once a month.	4	Item #18 on the Wright Map
Moon-A1-B	Moon-A1-B: Inaccurate description of moon's apparent motion but uses earth's rotation to explain. Moon orbits once a month.	1	<i>Level 3 combines accurate earth-motion with accurate apparent-motion; does not use moon's orbit in explanation</i> <i>Level 2 uses combines an accurate use of the earth-rotation moon's orbit (may or may not be</i>
Moon-A2-A	Moon-A2-A: Generally accurate description of the moon's apparent motion and uses the earth's rotation to explain. Moon's orbit is not a month.	3	
Moon-A2-B	Moon-A2-B: Inaccurate description of the moon's apparent motion and uses the earth's rotation to explain. Moon's orbit is not a month.	1	
Moon-A3-A	Moon-A3-A: Generally accurate description moon's apparent motion but uses earth's rotation and moon's 28 day orbit to explain daily motion.	2	
Moon-A3-B	Moon-A3-B: Inaccurate description moon's apparent motion but uses earth's rotation and moon's 28 day orbit to explain daily motion.	1	
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.	0	
Moon-B1-A	Moon-B1-A: Generally accurate description of the moon's apparent motion and uses the earth's rotation but the moon does not orbit and/or	3	

	stays on opposite side from the sun.		<i>accurate length) with an accurate apparent motion</i> <i>Level 1 – explanation combines earth’s rotation possibly with moon’s actual motion/orbit with an inaccurate path; OR earth’s rotation and moon’s up/down motion with accurate/inaccu rate path; OR an inaccurate earth’s rotation with an accurate/inaccu rate path</i> <i>Level 0 – Doesn’t use the earth’s motion in explanation and/or path is non-normative or moon doesn’t appear to move</i>
Moon-B1-B	Moon-B1-B: Inaccurate 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.	1	
Moon-B2	Moon-B2: Moon does not appear to move but uses earth’s rotation and moon does not orbit.	0	
Moon-B3	Moon-B3-A/B: Generally accurate/inaccurate description of the moon’s apparent motion but uses an inaccurate description of the earth’s rotation. Moon’s orbit may or may not be accurate. (Typo corrected, 2/28/10; B added 9/12/10)	1	
Moon-C1-A	Moon-C1-A: Generally accurate description moon’s apparent motion but uses earth’s rotation and inaccurate description of moon’s orbit to explain.	2	
Moon-C1-B	Moon-C1-B: Inaccurate description of moon’s apparent motion but uses earth’s rotation and inaccurate description of moon’s orbit to explain.	1	
Moon-C2-A	Moon-C2-A: Generally accurate description of moon’s apparent motion but uses earth’s rotation and moon’s up/down motion. Moon does not orbit.	1	
Moon-C2-B	Moon-C2-B: Inaccurate description of moon’s apparent motion but uses earth’s rotation and moon’s up/down motion. Moon does not orbit.	1	
Moon-C3	Moon-C#: Moon does not appear to move but uses earth’s rotation and inaccurate description of moon’s orbit to explain.	0	
Moon-D1-A	Moon-D1-A: Generally accurate description moon’s apparent motion but uses moon’s 28 day orbit to explain daily motion.	0	
Moon-D1-B	Moon-D1-B: Inaccurate description moon’s apparent motion but uses moon’s 28 day orbit to explain daily motion.	0	
Moon-D2-A	Moon-D2-A: Generally accurate description moon’s apparent motion but use moon’s orbit to explain. Orbit is not close to a month.	0	
Moon-D2-B	Moon-D2-B: Student gives inaccurate description of moon’s apparent motion and uses moon’s orbit to explain. Orbit is not close to a month.	0	
Moon-D3-A	Moon-D3-A: Student gives an accurate description of moon’s apparent motion but uses non-scientific motions of the earth and moon to explain (explanation is synthetic not naïve).	0	
Moon-D3-B	Moon-D3-B: Student gives an inaccurate description of moon’s apparent motion but uses non-scientific motions of the earth and moon to explain (explanation is synthetic not naïve).	0	
Moon E1-A	Moon-E1-A: Generally accurate description of moon’s apparent motion and explains that moon moves up and down. Moon does not orbit.	0	
Moon E1-B	Moon-E1-B: Student gives inaccurate description of moon’s apparent motion and explains that moon moves up and down. Moon does not orbit.	0	

Moon-F1	Moon-F1: Student does not think moon appears to move or actually moves.	0	
Moon-F2	Moon-F2: Student thinks the moon appears to move but does not describe and does not give an explanation for apparent motion.	0	

24. Secondary Stars Codes

Stars-A1-A	Stars-A1-A: Accurately describes stars' apparent motion and uses earth's rotation to explain this.	3	Item #19 on the Wright Map
Stars-A1-B	Stars-A1-B: Inaccurate description of stars' apparent motion and uses earth's rotation to explain this.	2	Level 3 combines accurate earth-motion with accurate apparent stars-motion
Stars-A2	Stars-A2: Accurately describes stars' apparent motion but uses inaccurate description of earth's rotation to explain this.	2	
Stars-B1-A	Stars-B1-A: Accurately describes stars' apparent motion and uses earth's rotation but also uses other inaccurate motions to explain this. (Updated 2/28/10)	2	
Stars-B1-B	Stars-B1-B: Inaccurately describes stars' apparent motion and uses earth's rotation but also uses other inaccurate motions to explain this. (Updated 2/28/10)	1	Level 2 uses accurate earth's rotation but inaccurate apparent motion of the stars (but they do appear to move) OR inaccurate explanation that includes a form of earth-rotation (and doesn't include stars' moving) with an accurate apparent motion
Stars-B2-A	Stars-B1-A: Accurately describes stars' apparent motion and inaccurately uses earth's rotation but also uses other inaccurate motions to explain this. (Updated 2/28/10)	1	
Stars-B2-B	Stars-B1-B: Inaccurately describes stars' apparent motion and inaccurately uses earth's rotation but also uses other inaccurate motions to explain this. (Updated 2/28/10)	1	
Stars-C1	Stars-C1: Stars do not move; student uses earth's rotation to explain that stars only set at end of the night.	1	
Stars-C2	Stars-C2: Stars do not move but student explains this with the earth's rotation	0	Level 1 – entire explanation based on earth's motion but either path is
Stars-D1-A	Stars-D1-A: Gives accurate description of stars' motion; explains by using the earth's orbit around the sun.	1	

Stars-D1-B	Stars-D1-B: Gives inaccurate description of stars' motion; explains by using the earth's orbit around the sun.	1	<i>inaccurate and/or rotation is not part of the explanation</i> <i>Level 0 – includes the stars' actual motion in explanation OR stars don't move</i>
Stars-E1	Stars-E1-A: Accurately describes stars' apparent motion but uses stars' actual motion to explain this.	0	
Stars-E2	Stars-E2: Gives inaccurate description of stars' motion; explains by using stars' actual motion to explain this.	0	
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.	0	

25. Overall movement and direction of objects' apparent motion	Level	Notes
ACM -A1: Sun, moon, and stars rise and set East to West	3	Item #20 on the Wright Map
ACM -B1: All rise/set but one may not have a path that goes across sky OR ACM -B2: Two rise/set across sky while third moves continuously	2	
ACM -C1: Sun and (moon OR stars) rise and set across sky	1	
ACM -D1: Sun generally accurate; moon and stars not accurate OR ACM -D2: No accurate paths	0	

Appendix B: Tertiary Codes as Levels for the Daily Celestial Motion Construct Map

The ranking of the following codes was informed by the *ConstructMap* analysis. Seven numerical values are indicated and were used in the statistical analysis described in the findings.

Numerical rank used in tests for significance	Description of coding scheme used in assigning the tertiary codes based on the secondary codes in Appendix A
	<p>Level 5 – Scientific Complete Explanations</p> <p>There is a more complex level of understanding beyond this level. But this is an acceptable level of scientific accuracy for elementary children and does not go beyond what our study assessed. Below I have indicated various levels of accuracy within the scientific view; thus children at this level still may have some alternative conceptions about astronomy.</p>
7	<p>Code 4A - The student describes the sun, moon and stars as rising and setting 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.</p> <p>a. Sun-A1-A, Moon-A1-A, (Stars-A1-A)</p> <p>b. Level 4A+: Same codes but students demonstrated all apparent motions in the same direction.</p>
6	<p>Code 4B - Student describes the sun, moon and stars as rising and setting 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 (such as believing the moon does not orbit or that the moon’s orbit is not 28 days).</p> <p>a. Sun-A1-A, (Moon-A2-A OR Moon-B1-A), (Stars-A1-A)</p> <p>b. Level 4B+: Same codes but students demonstrated all apparent motions in the same direction.</p>
	<p>Level 4 – Scientific Sun plus Moon OR Stars (accurately use Earth’s rotation to explain the Sun’s accurate apparent motion and either the moon or stars’ apparent motion)</p>
5	<p>Code 3A - Student uses earth’s rotation to explain a generally accurate description of the sun’s apparent motion and <u>either</u> the moon or stars, but not both.</p> <p>a. Sun-A1-A and [(Moon-A1-A, Moon-A2-A, Moon-B1-A), OR (Stars A1-A)]</p>
	<p>Level 3 – Scientific Sun mental models (accurately use Earth’s rotation to explain at least the Sun’s apparent motion)</p>
4	<p>Code 3B - Student uses the earth’s rotation to explain a generally accurate description of the sun’s apparent motion but neither the moon <u>or</u> the stars.</p> <p>a. Sun-A1-A and NOT [(Moon-A1-A, Moon-A2-A, Moon-B1-A) AND (Stars A1-A)]</p>
	<p>Level 2 – Synthetic Mental Models (Lower synthetic mental models - does not accurately use Earth’s rotation)</p> <p>This is a complicated area. There are many combinations of apparent motion descriptions and explanations involving the sun, moon and stars which children could have. These explanations will include some use of the earth’s motion. Most upper elementary children and adults will fall somewhere in this level. We have organized this starting with the accuracy of the sun’s apparent motion and explanation because in general, students are most accurate in this area. For nearly all students this organization appears to have made sense based on their conceptualization. Moon and star topics are usually less accurate.</p> <p>Below are “generalizations.” Students will have more complexities in the set of ideas they hold than can be described here. Therefore, I will also present the ordering of descriptions crossed</p>

	with explanations for each celestial object.
3	<p>Sub-Level 1: Entire explanation for sun's apparent motion is based on earth's motions; sun does not actually move. Code 2A - Student accurately uses the earth's rotation as well as other inaccurate explanations (such as earth's revolution around the sun, but not sun's own motion) for a <u>generally accurate description of the sun's apparent motion</u>. Student explains the generally accurate description of the moon <u>or</u> stars' apparent motion using the earth's rotation.</p> <p>a. (Sun-B1-A or Sun-B3-A or Sun-C1-A) and [(Moon-A1-A, Moon-A2-A, Moon-B1-A) OR (Stars A1-A)]</p> <p>Code 2B - Student accurately uses the earth's rotation as well as other inaccurate explanations (such as earth's revolution around the sun, but not sun's own motion) to explain a <u>generally accurate description of the sun's apparent motion</u> (this is the defining characteristic). Descriptions of the moon and stars' apparent motion, and explanations, also contain inaccuracies.</p> <p>b. (Sun-B1-A or Sun B3-A or Sun-C1-A) and NOT [(Moon-A1-A, Moon-A2-A) AND (Stars A1-A)]</p> <p>Code 2C - Student uses a generally accurate description of the earth's rotation but description of the sun's <u>apparent motion is inaccurate</u>. Student may also include other inaccurate explanations. Descriptions/explanations of the moon and stars' apparent motion also contain inaccuracies.</p> <p>c. (Sun-A1-B, Sun B1-B, Sun-B3-B, or Sun-C1-B) NOT [(Moon-A1-A, Moon-A2-A, Moon-B1-A) AND (Stars A1-A)]</p> <p>d. Level 2C *: Student gives an accurate description/explanation for moon and/or stars: [(Moon-A1-A, Moon-A2-A, Moon-B1-A) and/or (Stars A1-A)]</p> <p>Code 2D - <u>description of the sun's</u> apparent motion is accurate or inaccurate. Student gives an inaccurate description of the earth's rotation and may include other inaccurate explanations. Descriptions/explanations of the moon and stars' apparent motion also contain inaccuracies.</p> <p>e. (Sun-B2-A, Sun B2-B, Sun-B4-A, Sun-B4-B), NOT [(Moon-A1-A, Moon-A2-A, Moon-B1-A) AND (Stars A1-A)]</p> <p>f. Level 2D *: Student gives an accurate description/explanation for moon and/or stars: [(Moon-A1-A, Moon-A2-A, Moon-B1-A) and/or (Stars A1-A)]</p> <p>Code 2E - Student uses the earth revolving around the sun to explain a <u>the sun's apparent motion</u>. Descriptions of the moon and stars' apparent motion, and explanations, also contain inaccuracies.</p> <p>g. (Sun-B5-A, Sun-B5-B) and NOT [(Moon-A1-A, Moon-A2-A, Moon-B1-A) AND (Stars A1-A)]</p>
2	<p>Sub-Level 2: Explanation for sun's apparent motion combines the sun's actual motion with the earth's motion.</p> <p>Code 2F - Student gives a generally accurate/inaccurate description of the sun's motion and explains with earth's rotation and the sun revolves around the earth (or sun moves up and down. Moon (and/or) stars may contain other inaccuracies (Possibly may have to create sub level based on further analysis of the data. For now go with both have inaccuracies)</p> <p>a. (Sun-CA-1, Sun C1-B) and NOT [(Moon-A1-A, Moon-A2-A, Moon-B1-A) AND (Stars A1-A)]</p> <p>b. Level 2B *: Student gives an accurate description/explanation for moon and/or stars: [(Moon-A1-A, Moon-A2-A, Moon-B1-A) and/or (Stars A1-A)]</p>
	<p>Level 1 – Naïve world view (1) This level is for children who are not using the earth's rotation as part of their explanation.</p>
1	<p>Code 1A - The child believes that the sun's apparent motion is caused by the sun's actual motion. However, they have adopted a more sophisticated description of why the moon and/or the stars appear to move by using the earth's rotation to explain one or both of those other patterns of motion.</p> <p>a. Either [Sun-D1, Sun-D3, or Sun-C2] and NOT [Moon-D1-A, D2-A, E1-A, E2-B, F1 or F2, And/Or Stars-E1, E2, or E3.]</p>

	<p>Code 1B - Children understand that the sun and moon rise and set on opposite sides of the sky. But they use the object's own motion (such as, 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 (or this motion is not seen as connecting to the apparent motion of celestial objects).</p> <p>b. Sun-C2-A, (Moon-D1-A or D2-A), (Stars-E1, E2, or E3).</p> <p>Code 1C - The child believes that the sun and moon appear to rise and set (or go up/down) because of their own up/down motion. Stars do not move, move a little bit, or move due to their own motion. The earth does not move (or this motion is not seen as connecting to the apparent motion of celestial objects).</p> <p>c. (Sun C2-B, Sun-D1-A or D1-B), Moon-E1-A, (Stars-E1, E2, or E3).</p> <p>Code 1D - Pre-observational view: The child does not describe the sun as rising and setting and the explanation either is the sun's own motion up and down or the explanation is not based on a 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 appear to move.</p> <p>d. Sun-D2, (Moon-E2-B, F1 or F2), Stars-E3.</p>
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