STUDENTS’ DEVELOPMENT OF ASTRONOMY CONCEPTS

ACROSS TIME

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Astronomy and Education)
in The University of Michigan
2006

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To my parents: Susan and Gregory Plummer
For their endless support and encouragement
ACKNOWLEDGEMENTS

Many people have helped me throughout this process of creating my place in astronomy and education. I would like to thank my advisor and co-chair of my dissertation, Joe Krajcik, for all of the help and support he has provided, allowing me to develop and execute this project. I would also like to thank my astronomy advisor and co-chair of my dissertation, Mario Mateo, who encouraged me to follow my interests in graduate school. My cognate member, Scott Paris, provided valuable advice in the development of this project and the writing of this dissertation. And finally, this project would not have been possible without the assistance of Matt Linke, Director of the Exhibit Museum Planetarium. I am grateful for all of his support and friendship throughout the 9 years I have worked in the planetarium, and for building the mini-dome used in the interviews for this project.

Many others have helped facilitate the completion of this project: Amy Harris, Director of the Exhibit Museum allowed me to use the planetarium for my dissertation; Linda Heywood, Office Manager at the Exhibit Museum, helped me find teachers to contact for this study; Molly Yunker, for completing inter-rater reliability; Lingling Zhang, for statistical advice; the teachers and principals who allowed me to have access to their students; and the students for all of their wonderful ideas. During this project I was supported through my work on two NSF funded programs: The Center for Curriculum Materials in Science and Project Based Inquiry. I also received a Spencer
Mini-grant from the School of Education to pay for the buses to bring the students to the planetarium.

I would like to thank all of my colleagues and professors in both Astronomy and Education who have supported my learning process along the way, especially: Alex Athey, Anne Marie Palinscar, Becky Stanek, Beth Kubitsky, Betsy Davis, David Fortus, Jay Fogleman, Jeff Hill, Kate McNeill, Sarah Ragan, Susanna Hapgood, and Barbara Eckstein for suggesting I go into Education in the first place. There is no way to express the importance of my experience with all of the people involved in the Exhibit Museum: staff, docents, and visitors. I am thankful for the chance to work with all of the thousands of children and adults through my work at the Planetarium and Exhibit Museum, and the friendships I have formed with my fellow planetarium operators, especially Jesse Tryon. Finally, I would like to thank my good friends Sarah Thompson, Ronnie Order, Josie Chang-Order, and Adam Boisvert for all those dinners at my place.
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ABSTRACT

The National Science Education Standards (NRC, 1996) recommend that students understand the apparent patterns of motion of the sun, moon and stars visible by the end of early elementary school. However, little information exists on students’ knowledge of apparent celestial motion or instruction in this area. The goals of this dissertation were to describe children’s knowledge of apparent celestial motion across elementary and middle school, explore early elementary students’ ability to learn these topics through planetarium instruction, and begin the development of a learning progression for these concepts. First, third, and eighth grade students (N=60) were interviewed using a planetarium-like setting that allowed the students to demonstrate their ideas both verbally and with their own motions on an artificial sky. Analysis of these interviews suggests that students are not making the types of observations of the sky necessary to learn apparent celestial motion and any instruction they may have received has not helped them reach an accurate understanding of most topics. Most students at each grade level could not accurately describe the patterns of motion. Though the older students were more accurate in most of their descriptions than the younger students, in several areas the eighth grade students showed no improvement over the third grade students. The use of kinesthetic learning techniques in a planetarium program was also explored as a method to improve understanding of celestial motion. Pre- and post-interviews were conducted with participants from seven classes of first and second grade students (N=63). Students
showed significant improvement in all areas of apparent celestial motion covered by the planetarium program and surpassed the middle school students’ understanding of these concepts in most areas. This suggests that students in early elementary school are capable of learning the accurate description of apparent celestial motion. The results demonstrate the value of both kinesthetic learning techniques and the rich visual environment of the planetarium for improved understanding of celestial motion. Based on the results of these studies, I developed a learning progression describing how children may progress through successively more complex ways of understanding apparent celestial motion across elementary grades.
CHAPTER 1
INTRODUCTION

Children growing up today have fewer opportunities to observe and reflect on the sky, both in the day and the night, compared with years past. Our society no longer requires that we learn about the apparent motion of the sun and stars to observe the passage of time or know when to plant and harvest crops. Yet a basic knowledge of astronomy includes knowledge of the simple patterns of motion exhibited by the sun, moon and stars that are observable from the surface of the earth. This dissertation examines children’s knowledge of the motion of the sun, moon and stars from their perspective on the earth, investigates instruction designed to help students learn these concepts, and develops a progression describing how children may move towards a more scientific understanding of apparent celestial motion.

Rationale

The challenges of learning apparent celestial motion

The primary subject matter addressed in this study of children’s knowledge is apparent celestial motion. This can be defined as any of the observable patterns of motion of the sun, moon and stars that occur on a daily, monthly and yearly pattern. These patterns of motion are apparent because we are not observing the actual motion of these celestial objects from our vantage point on the earth’s surface. The patterns of motion we observe result from what may be termed the actual celestial motion: the
rotation of the earth, orbit of the moon around the earth, and orbit of the earth around the
sun. Due to the earth’s rotation, the sun, moon and stars all appear to slowly rise and set
throughout the day and night (though some stars appear to circle about a point on the sky
where the earth’s north or south pole point in space). The sun’s position throughout the
day and length of day are influenced by the earth’s tilt with respect to its orbit about the
sun which results in the path of the sun shifting higher in the summer and lower in the
winter. The moon’s path changes due to its orbit around the earth; this causes the moon
to rise about 50 minutes later every night as well as slowly show more or less of the side
illuminated by the sun (resulting in the phases of the moon).

Thus a full scientific understanding of the topic of celestial motion includes both
the observable patterns of change in the sun, moon and stars’ locations as well as the
explanations for those changes. Knowledge of the earth’s rotation or its orbit around the
sun has little value if one cannot use those concepts to explain and predict astronomical
phenomena. The most accessible of astronomical phenomena available to students are
those they can observe from their own earth-based perspective such as the rising and
setting of the sun or moon.

The actual motion of the earth and moon are not intuitive concepts for children or
adults. We are not able to directly observe or experience the phenomena of the earth
rotating or the moon orbiting the earth. We rely on observations of the effects that these
actual motions have on what we can observe from the surface of the earth. Historically,
knowledge of the actual motions of celestial objects were first described by astronomers
attempting to explain what people could observe in the patterns of apparent motion of the
sun, moon, stars and planets\(^1\). However, observing and learning the patterns of apparent celestial objects pose their own set of challenges. First, all of these motions occur over long periods of time: hours in the case of the daily motion of the sun, moon and stars; daily for the shift in the moon’s appearance and rise/set time; monthly for the slow change in the sun’s path across the seasons and the change in the constellations we see each night. Second, tracking these motions requires concerted effort to notice and recall positions with respect to landmarks on the horizon. Third, these changes are often occurring when many people are not outside observing the sky such as at night or during inclement weather. For most, making the observations necessary to track the patterns of change in apparent celestial motion will require the guidance of someone with more expertise.

For these reasons, it is unlikely that most children have made the observations necessary to learn the details of apparent celestial motion. Students have seen the sun in the sky during the day and probably seen the moon at night. They may or may not have noticed that the moon is also visible at times during the daytime. And while most have at least caught a glimpse of the stars at night, the vast array of stars makes it exceptionally challenging for children, and many adults, to notice any change in stars that are seen at different times of night or different nights of the year. Their observations are also limited, and potentially influenced, by weather patterns, geographic location (such as near the ocean or mountains), as well as their understanding of the concepts of the earth and sky.

\(^1\) Technically, the five planets visible without a telescope also exhibit apparent celestial motion because they also appear to rise and set as well as move against the background of stars. However, this is a more advanced conceptual area than is addressed in this dissertation.
Children may not be receiving accurate instruction from parents and other adults as well. Just as with children, adults in today’s culture are unlikely to be making the types of observations needed to fully understand apparent celestial motion. Studies of college students and pre-service teachers’ knowledge of astronomy reveal many alternative ideas (Atwood & Atwood, 1996, 1997; Parker & Heywood, 1998; Trundle, Atwood, & Christopher, 2002; Zeilik & Bisard, 2000). This suggests that they may also have many of the same alternative ideas about apparent celestial motion. From this, we may also expect that students are not learning about these concepts at home or other settings.

**Rationale for learning concepts of apparent celestial motion**

There are several reasons why children may benefit from learning about apparent celestial motion in elementary school. First, an accurate understanding of the observable aspects of astronomy, those visible without aid of camera or telescope, from our own earth-based perspective is one aspect of understanding recommended for a scientifically literate individual. Project 2061, a long-term initiative of the American Academy for the Advancement of Science, published Science for All Americans (1989). This document contains recommendations for the essential areas of understanding in science and technology for all citizens in today’s world. One of these essential areas of understanding for the scientifically literate individual is the noticeable effects of the motion of the earth and moon. It was knowledge of the patterns of celestial motion that provided the basis for much of the development of human understanding of more advanced concepts such as rotation, revolution, orbital mechanics, the universal theory of gravity and the speed of light.
The second reason for focusing on apparent celestial motion in elementary education is the connection between apparent and actual celestial motion. Learning about the observable aspects of celestial motion provides a reason to learn the unobservable explanations for these phenomena. In school, most instruction fails to make the connections between the observed motions in the sky and the deduced motion of the planets, sun and moon from a heliocentric perspective (outside of the earth-based perspective; Nussbaum, 1986). Instruction that primarily focuses on the heliocentric motions is not only unlikely to improve knowledge of geocentric motion; it may also facilitate students’ in creating alternative ideas about celestial objects and their motion. If students have a clear knowledge of the patterns of celestial motion, they will have a reason to learn about the heliocentric motions of these celestial objects in a context in which the underlying cause of motion can be explained using evidence from our observations. Once students are familiar with the rising and setting motions of the sun, moon and stars they will have a reason to understand the rotation of the earth. If students have learned that the moon rises later everyday they will have a reason to try to understand the orbit of the moon.

Learning about the apparent motion of the sun may also help students understand other important topics such as the seasons and phases of the moon. The seasons are the result of the earth’s tilted axis with respect to its orbit around the earth. This concept is too challenging to expect elementary students to fully master. However, the important effects of the earth’s tilt that result in the seasonal change are those that are less abstract: the changing altitude of the sun and the length of the sun’s path. If students first learn about how the changes in the sun’s path affect the seasons they may find understanding
the full explanation of the seasons more accessible, though further research needs to be
done to confirm this idea. Similarly, learning the observable pattern of the change in the
phases of the moon may help students later learn how to explain these patterns.

Both the National Science Education Standards (NSES; National Research
Council, 1996) and the Benchmarks for Science Literacy (Benchmarks; AAAS, 1993)
include the patterns of celestial motion as part of the learning goals for children in early
elementary school. For the K-4 grade levels, the following astronomy objectives are
listed in the NSES:

1. The sun, moon, stars, clouds, birds, and airplanes all have properties, locations,
   and movements that can be observed and described.
2. Objects in the sky have patterns of movement. The sun, for example, appears to
   move across the sky in the same way every day, but its path changes slowly over
   the seasons. The moon moves across the sky on a daily basis much like the sun.
   The observable shape of the moon changes from day to day in a cycle that lasts
   about a month.

Both objectives relate to observations of the sky from an earth-based perspective. These
concepts are also recommended for study at this early age in Benchmarks:

1. The sun can be seen only in the daytime, but the moon can be seen sometimes at
   night and sometimes during the day. The sun, moon, and stars all appear to move
   slowly across the sky. (Grades K-2)
2. The moon looks a little different every day, but looks the same again about every
   four weeks. (Grades K-2)
3. The patterns of stars in the sky stay the same, although they appear to move
   across the sky nightly, and different stars can be seen in different seasons. (Grades
   3-5)

Based on the NSES and Benchmarks, the recommendations for what elementary
students should be studying in observational astronomy can be summarized as follows:

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

These recommendations for early elementary students focus solely on changes in the sky that are observable and not the explanations for these motions.

The *NSES* and *Benchmarks* provide a summary of objectives relating to apparent celestial motion that are intended to help in the design of curricula and assessments for early elementary students. However, these documents only give us brief goal statements that lack support from research on children’s knowledge of these topics and elaboration on the steps that students may move through in the process of learning these concepts. Smith, Wiser, Anderson and Krajcik (2006) suggest that by using research on children’s reasoning and learning in science we can elaborate on the *NSES* and *Benchmarks* in ways that can be used to help teachers, curriculum developers, and assessment writers in improve their practice. These elaborations would create *learning progressions*:

“descriptions of successively more sophisticated ways of reasoning within a content domain based on research syntheses and conceptual analyses” (p. 3). Such a progression would be a useful tool in considering how to guide the difficult restructuring required for much of science learning. Current science curricula are rarely designed with this kind of careful restructuring in mind (Kesidou & Roseman, 2002).

It is important to note that a learning progression is not an inevitable progression that all students will move through towards a scientific understanding (Smith, Wiser, Anderson & Krajcik, 2006). Rather, how children progress depends on the instruction they receive. Further, a learning progression is only one of many possible pathways a student may move through towards a more sophisticated view of a concept. Finally,
without long-term longitudinal studies of the development of children’s understanding, we can only propose learning progressions that are inferential, based on snap-shots of different populations or grade levels.

Learning progressions are built on the “big ideas” which are central principles of the domain. By focusing on these big ideas, coherent curricula can be developed and assessments can be aligned to the central aspects of scientific understanding in each domain. Students may spend years learning progressively more sophisticated ways of reasoning about these big ideas in order to reach a scientific understanding of the concepts. According to Smith, Wiser, Anderson and Krajcik (2006), big ideas have the following characteristics:

1. Central to their discipline with broad explanatory power;
2. Understood in progressively more sophisticated ways;
3. And lay the foundation for continued learning.

Smith et al. developed a detailed learning progression for grades K-8 around the big ideas of matter and atomic molecular theory.

In the domain of celestial motion, there are big ideas that relate to apparent celestial motion and big ideas that relate to the explanation for that apparent motion. While these two areas are highly inter-related, in this dissertation I will develop learning progressions that elaborate upon the big ideas of apparent celestial motion. In the future, with additional research on children’s understanding, it will be possibly to describe learning progressions that consider both of these ways of understanding celestial motion. The big ideas described in this dissertation are:
1. The sun, moon, and stars all appear to move slowly across the sky with a regular pattern of motion.

2. The appearance of the moon changes over the course of a month.

Creating a learning progression requires a basis in research that provides empirical evidence about children’s learning about celestial motion. A learning progression that is grounded in empirical evidence is developed by considering what children know about these topics at different grade levels as well as what they are capable of with well-designed instruction.

This presents a problem. At present, there is a scarcity of research on children’s knowledge of apparent celestial motion. A review of existing astronomy education literature performed by Adams and Slater (2000) found little existing literature on children’s ideas about apparent celestial motion, especially at the grade levels that these topics are recommended for students. For this reason, Adams and Slater recommend that “the first task for the lower grades is to evaluate student geocentric conceptions of the day and night sky. Because of an increasing distance between youth and the environment, the results of such a study are likely to be very different than studies would have found thirty years ago” (p. 12). Since the time of that review there have been no additional studies to shed light on this problem.

Prior research in other areas of astronomy education may provide some information on what children and adults know about the patterns of apparent celestial motion. For example, Vosniadou and Brewer’s (1994) study of elementary students’ ideas about the day/night cycle suggests that many young children believe the sun and moon are actually circling around the earth and thus they also believe that the apparent
motion is the actual motion. These interviews also suggest that children may believe we will only see the moon appear to move across the sky at night. Sharp (1996)’s study of 10- and 11-year old children’s ideas about the sun, moon and stars suggests that elementary students’ knowledge of apparent celestial motion decreases as you move from topics about the sun, to the moon, and finally the stars. I will give a full analysis of what we can deduce about children’s understanding of apparent celestial motion from these and other studies in Chapter 2.

**Instruction for apparent celestial motion**

If understanding apparent celestial motion is to be a goal of elementary science education then instructional techniques designed for these topics need to be evaluated by the educational research community in order to determine what may be successful in helping students learn at different grade levels. However, there has been even less of a focus in the astronomy education community on research that connects theory to practice than on describing students’ prior knowledge and alternative ideas (Bailey & Slater, 2003). And those studies on elementary students learning about astronomy have primarily investigated topics relating to the *explanations* of observable phenomena such as the phases of the moon with third grade students (Staley, Krockover, & Shepardson, 1999) and fifth grade students (Barnett & Morran, 2002) in the United States, the day/night cycle with fifth grade students in Cyprus (Diakidoy & Kendeou, 2001) and the solar system with Year 5 and 6 students in England (Sharp & Kuerbis, 2005).

Research on children learning about science suggests that what students learn is highly influenced by their prior knowledge and beliefs about the world (Bransford, Brown, & Cocking, 1999). This suggests that successful instruction is designed to
consider how children’s prior knowledge will influence how they interpret new ideas. In order for this to occur, we must first assess what children already know about apparent celestial motion and then consider what types of instruction may successfully build upon those pre-existing ideas and what might be necessary in order to help children reject and replace problematic concepts. There may also be skills and abilities that are prerequisite to learning about apparent celestial motion that early elementary students have not yet developed, such as the ability to describe positions and directions or how objects may appear to move so slowly that their motion is not immediately perceivable. Considering how these pre-requisite skills may affect what children learn can also be used to improve instructional design.

One of the biggest challenges in developing curriculum that helps children learn about apparent celestial motions is determining how to present representations of the concepts that are meaningful and accessible to children. For students to make the observations of the sun necessary to describe its apparent path across the sky requires that they be able to record the progression of the sun at several points through out the day. Tracking this motion for the moon is complex because the moon is often only in the sky for part of a school day and the rise and set time for the moon change on a daily basis. The stars are even more challenging because plotting their motion requires both the ability to recognize individual stars among the thousands visible in the sky and the observations must be made while most children are asleep.

There is an instructional setting that can demonstrate the motion of celestial objects on command. The planetarium allows students to view the motion of celestial bodies in a way that they are unable to do on their own because the planetarium
instrument is able to project a days worth or even a years worth of motion in a matter of a few minutes. The planetarium is a wonderful tool to use in the teaching of objects and motions in the sky from an earth-based perspective. It can be used to help students identify and learn about the familiar objects of the day and night. The planetarium provides an environment that demonstrates new concepts in ways that can be connected with students’ previous knowledge of the sky and celestial objects by showing images of these familiar objects in ways that mimic the actual sky.

Successful planetarium instruction has the potential to reach a wide audience. Education in the planetarium impacts both school children and the public because planetariums are found in museums, science centers and schools around the world. Over a decade ago, the President of the International Planetarium Society, in describing the estimated 2000+ planetariums in existence world-wide, wrote: “In all of these theaters with all of these instruments in all parts of the world, it has been estimated that 20 million people visit planetariums each year” (Manning, 1995, p. 81). Unfortunately, there is limited research on the success of using planetarium programs to improve students’ knowledge of astronomy.

Though the planetarium appears to be perhaps the ideal setting for learning about apparent celestial motion and has the potential for widespread impact, the lack of research on planetarium instruction is problematic. For this reason, a second goal of this dissertation will be to investigate the use of the planetarium in helping children learn about celestial motion. This requires careful consideration of the type of instruction that will engage the students and match well with the target concepts. It is widely accepted that in order for students to learn new concepts they need to be engaged with the
instruction in a meaningful fashion. In the planetarium community, participatory programs have been developed to include active forms of learning, opposed to the more traditional and passive style of planetarium presentation. In a participatory program the audience is actively engaged in thinking about the concepts through activities in which they discover meaning for themselves, predict possible outcomes, and engage in extensive verbal interaction with the planetarium operator and other audience members (Friedman, Schatz, & Sneider, 1976).

In this dissertation I will investigate the use of a participatory planetarium program designed to teach early elementary students the concepts central to apparent celestial motion. One of the challenges in designing this program was to ensure that all the students would be engaged in the instruction in a way that was consistent with the concepts of apparent celestial motion and also considered children’s prior knowledge about these topics. To help guide children in learning about celestial motion in the planetarium I incorporated the use of their own bodily motions in the program: kinesthetic learning techniques (KLT). KLTs describe two different ways the children were using their own motion. First, the children used their own motion to make predictions about what the apparent motion of the sun, moon and stars would look like in the sky, based on their own prior knowledge or previous observations made in the planetarium. Second, the children were asked to point to and then follow the motion of objects in the planetarium. These KLTs were used to help focus the children’s attention on key topics of the planetarium program.
Research Questions

The purpose of this dissertation is to begin to describe a learning progression for apparent celestial motion that is grounded in research on how children develop these concepts. Because there have been no systematic studies that focus on how children describe apparent celestial motion, the first piece of this dissertation will examine children’s knowledge of these topics in elementary and middle school. This study will illuminate trends in how children’s knowledge of apparent celestial motion progresses across the grade levels based on their observations of the world and cultural influences, not the result of direct instruction on these concepts because most science instruction in astronomy is not designed to help students learn these concepts. Students in three different grade levels were interviewed: first, third, and eighth. The first and third grade students were chosen because these students fall in the grade-range suggested by NSSE\textsuperscript{S} and Benchmarks for learning apparent celestial motion. The eighth grade students were added to see if children show improvement in these topics after early elementary school.

In Chapter 4, I will describe the results of this first study, guided by the following research questions:

1. What are students’ conceptions of the patterns of motion of the sun, moon, and stars, as viewed from the earth?

2. Do students’ conceptions of the motion of the sun, moon, and stars change with grade level?

In the second study of this dissertation I will describe the results of a planetarium program designed to improve students’ understanding of apparent celestial motion. First and second grade students were interviewed before and after the planetarium program.
This grade range was chosen because the *NSES* and *Benchmarks* recommend that children learn most of the concepts of apparent celestial motion in early elementary school. This study will demonstrate whether or not understanding of the apparent motion of the sun, moon and stars is attainable by early elementary students with planetarium instruction designed to incorporate the children’s own motions in the learning experience.

The research questions that guided this study were chosen based on the nature of the planetarium program. Six key ideas about celestial motion were covered using KLTs: path of the sun in summer, path of the sun in winter, comparison of the path of sun in summer and winter, path of the moon across the sky, the motion of the stars and what happens to make it day. Additional subjects were covered during the program that did not include corresponding KLTs: changing phases of the moon, appearance of the moon during daytime, and appearance of the stars during the daytime. Students were interviewed before and after the planetarium program about these concepts, as well as a few concepts that were not goals of the planetarium instruction. These were topics that related to the students’ understanding of the earth-sun-moon system from outside of an earth-based perspective and involved the invisible explanations for celestial motion to fully answer: location of the moon when not in the sky and location of the sun at night. These questions were included in the interviews because they relate to apparent celestial motion and could be used to examine whether or not the planetarium program had an influence on how children explain apparent celestial motion.

This second study, described in Chapter 5, was guided by the following three research questions:
1. Do students who participate in a planetarium program that utilizes kinesthetic learning techniques (KLTs) improve their knowledge of the patterns of motion of celestial objects?

2. Did students learn about addition topics covered in the planetarium program that were not taught by the use of KLTs?

3. Did students explanations for the disappearance of the sun and moon from the sky change as a result of the planetarium program?

The results of Study A will be used to inform the development of a learning progression on apparent celestial motion, in combination with a careful conceptual analysis. This learning progression will then be compared to the results of Study B, the change in children’s knowledge after instruction on apparent celestial motion, to determine how instruction may impact students’ development of understanding in this area.

**Summary and Overview**

In this chapter, I began by pointing out the importance of understanding apparent celestial motion as a key piece of scientific literacy and a connection to more advanced topics of astronomy. I have proposed that creating learning progressions for apparent celestial motion will be a useful tool in future development of curriculum and assessment work (Smith, Wiser, Anderson & Krajcik, 2006). However, the lack of research in children’s knowledge of apparent celestial motion and instructional strategies limits attempts to create such a learning progression. Therefore, this dissertation is composed of two related studies. The first study examines children’s knowledge of apparent celestial motion in elementary and middle school. The second study examines children
learning about the motion of the sun, moon and stars in a planetarium program that uses kinesthetic learning techniques. Together, the results of these two studies will allow me to make suggestions about how children may move through a progression of ideas in apparent celestial motion and how understanding can be influenced by well designed instruction.

Chapter 2 examines what we can expect children to know about apparent celestial motion based on previous work in areas of astronomy relating to celestial motion such as the day/night cycle, phases of the moon and the seasons. I will also describe previous research that supports the use of kinesthetic learning techniques in the planetarium and conceptual change theories that influenced the analysis of the results of my studies. Chapter 3 provides a description of the research subjects and methodology used in the both parts of the dissertation: a cross-grade study of children’s knowledge of celestial motion and the study of kinesthetic learning techniques in the planetarium. It also presents a full description of the planetarium program used in the second study. Chapter 4 describes the results of the first study and answers the research questions outlined above concerning the nature of children’s knowledge of celestial motion and any progression seen across the grade levels. Chapter 5 presents the results of analysis of pre/post interviewed conducted with the first and second grade students who attended the planetarium program. Chapter 6 summarizes the findings of both parts of this study by developing the learning progression for apparent celestial motion. I will also discuss the implications of this work on instruction and makes suggestions for future research.
CHAPTER 2
REVIEW OF THE LITERATURE

Overview

In the previous chapter, I introduced the research problem as both the need to understand children’s prior knowledge and to develop and evaluate instruction designed to improve children’s understanding of celestial motion. This work can be used to create a learning progression that describes successively more sophisticated ways that learners may understand the big ideas of celestial motion (Smith, Wiser, Anderson & Krajcik, 2006). The learning progression may then become a tool to help educators consider “what it means to move towards a more expert understanding” of the field (p.3).

Recent reviews of astronomy education research (Adams & Slater, 2000; Bailey & Slater, 2003) have shown a lack of research on students’ knowledge of apparent celestial motion as well as a lack of research-based instruction in this area. Knowledge of the earth-based perspective provides a basis for further learning of the deduced, heliocentric topics and is the beginning for scientific literacy in astronomy. Despite this deficit in the research literature, the concepts of apparent celestial motion are recommended by both the National Science Education Standards (NSES; NRC, 1996) and the Benchmarks for Science Literacy (Benchmarks; AAAS, 1993) for the early elementary grades.
In this chapter, I will begin by discussing what existing research on children and adults’ knowledge of astronomy suggests about what children may believe about the apparent motion of the sun, moon and stars, as well the challenges that children face in learning these concepts. Much of the existing literature on elementary students’ understanding of astronomy has focused on how to explain observable phenomenon (such as the reasons for the day and night cycle, seasons, or the phases of the moon), or concepts that are not directly observable (such as shape of the earth or the nature of the solar system). These studies can help us predict what students may know about apparent celestial motion and reveal the areas that remain unexplored.

In the second part of this chapter, I will provide support for the instructional design used in Study B of this dissertation. I will describe a theoretical framework based on a conceptual change view of learning that will be used to consider the results of interviews with students about their ideas of celestial motion and from which the instructional context was developed for this study.

**Children’s Understanding of Celestial Motion**

**Prerequisite knowledge and skills for learning apparent celestial motion**

Understanding apparent celestial motion requires that young children have the ability to understand and describe the types of motion exhibited by the sun, moon and stars, as viewed by observers on earth. This may present a challenge to students beyond their normal ability to describe the location and motion of earth-bound objects that they encounter on an everyday basis. One of the prerequisite skills required to understand celestial motion is the ability to recognize and describe a celestial object’s location in the
sky, including altitude and direction. This is consistent with the NSES’s recommendations on aspects of learning about motion for students in grades K-4:

- The position of an object can be described by locating it relative to another object or the background.
- An object's motion can be described by tracing and measuring its position over time.

However, making these types of observations for the sun, moon and stars may be more difficult for children than tracking and describing motion of terrestrial objects because these objects appear against the sky and not near familiar objects on the ground.

Another challenge presented by apparent celestial motion is that it occurs on a much longer time scale than students normally observe motion (Viglietta, 1986). An observation of the location of the sun does not immediately reveal that it’s location in the sky is changing. This will presumably create a problem for young children when they are trying to answer questions about the patterns of motions of the sun, moon and stars. Viglietta suggests that children may not think that “displacement” implies motion. Rather, the students may simply believe the objects appear and disappear from the locations in which they are observed. To move beyond observations of the location of the sun, moon and stars will require that students be able to keep track of positions over an extended period of time and then move beyond those observations to infer motion.

It is interesting to note that, in the section of the Benchmarks describing what students should be learning about motion, the relevant benchmark of motion related to the concept of the apparent motion of the sun, moon and stars is found in the section for grades 3 through 5: “How fast things move differs greatly. Some things are so slow that their journey takes a long time; others move too fast for people to even see them” (p. 89). Placing this level of understanding at the upper elementary level does not support the
recommendation that children should learn that the “sun, moon and stars all appear to move slowly across the sky” by the end of second grade (p. 62). The Atlas of Science Literacy² (2001) does place this concept at the K-2 grade level. However, the Atlas does not connect this concept area to the relevant astronomy benchmarks but can be found linked to geological changes.

**Reasoning from the actual motion of the earth**

Another way for students to understand apparent celestial motion is for them to reason from the concepts of heliocentric motion (the rotation of the earth and orbit of the earth) to what we would observe from the earth’s surface. For example, if a student understands that the earth spins then he or she may reason that the moon will appear to rise and set because of this rotation. This brings up the question of whether or not elementary students are capable of switching between these two frames of reference. In other words, can children imagine what the motion of the objects in the sky looks like from the earth’s surface if they can imagine what the rotating earth looks like from a perspective outside of the earth?

Research into the development of spatial perspectives has shown that children as young as 5 ½-years-old have already developed some of the skills necessary to imagine objects as seen from different perspectives. Studies of 4 ½, 5, and 5 ½-year olds demonstrate that the oldest of these children can already grasp the three spatial perspective-taking rules: (1) objects will appear the same to two different viewers observing from the same location, (2) heterogeneous-sided objects will appear different

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² The Atlas of Science Literacy (AAAS, 2001) is a re-working of *Benchmarks for Science Literacy*. It organizes and links specific benchmarks across grade levels to be used as a tool for curriculum planners and developers.
from viewers looking from different locations, and (3) homogeneous-sided objects (such as a cylinder or a sphere) will appear the same to two people viewing from different locations (Flavell, Flavell, Green & Wilcox, 1981). They further suggest that the children in the study were using “rule knowledge” and not attempting to make the mental computations necessary to check their ideas. Although children may be able to develop the understanding of the rules that govern perspective-taking by a young age, this does not necessarily lead to the development of rules to predict and describe motion observed from different perspectives. Students who have learned that the motion of the sun across the sky is a result of the spinning earth may not be able to translate that knowledge to an accurate description of the apparent motion of the sun. Also, they may not automatically translate this idea to the motion of the moon or stars.

But perhaps it is not a matter of children’s inability to imagine the concepts of celestial motion from different perspectives that limits them but rather it may be a problem of depth of knowledge. Early elementary students do not have the depth of knowledge of the domain from which to build more abstract concepts. Flavell, Miller and Miller argue that for children, “expertise is particularly important because their more abstract knowledge allows them to generate causal explanations about that domain. These causal explanations in turn constrain the inferences they generate about novel instances (1993, p. 144).” Thus children may be unable to reason between geocentric and heliocentric frames of reference due to their lack of knowledge of the nature of the objects involved and the observable properties pertaining to the subject, and not simply their developmental level. This lack of knowledge may include a full understanding of the shape of the earth and their location on that earth, how the curvature of the earth may
affect their observations, the distance and nature of the stars, and the difference between the orbits of the moon and earth and the rotation of the earth.

The shape of the earth concept may in fact be an important factor in determining whether children can move between the sun-moon-earth system frame of reference and the earth-based frame of reference. Vosniadou and Brewer (1992) investigated first, third and fifth grade students’ ideas about the shape of the earth. They found that the percentage of students holding a non-scientific understanding of the earth’s shape decreased from 85% in first grade, 60% in third grade, to 40% in fifth grade. These alternative ideas about the earth’s shape include a flat earth, dual earths, and the idea that we live on a flat surface within a spherical earth. Their results are consistent with other studies of elementary students’ notions of the earth’s shape (Baxter, 1989; Nussbaum & Novak, 1976; Nussbaum, 1979; Sneider & Pulos, 1983; Sneider & Ohadi, 1998). Based on these and other studies of children’s understanding of the shape of the earth, Agan and Sneider (2003) suggest that children are not able to master the full concept of the earth’s shape until fourth or fifth grade. This lack of scientific understanding of the shape of the earth among most early elementary students and many upper elementary students may make understanding the consequences of the earth’s rotation to our observations of apparent celestial motion a challenge for these students.

**Previous studies relating to apparent celestial motion**

A thorough review of the astronomy education literature revealed only two studies that focused on the appearance of the sky from an earth-based perspective and neither of these studies examined the grade levels in which these topics fall in *NSES* or *Benchmarks*. Sharp (1996) interviewed Year 6 students (10- and 11-years-old) in
England about their knowledge of the sun, moon and stars as well as the earth, day and night, seasons and the solar system. The methodology of this study limits the usefulness of the results in fully understanding the children’s understanding of apparent celestial motion. The students answered questions about the apparent motion of the sun, moon, and stars using gestures and drawings. The author primarily reported whether or not they seemed to indicate a pattern of motion similar to the actual motion, rather than a rich description of the types of answers the students’ gave about this motion. The second study investigated the astronomy knowledge of primary school teachers in England (Mant & Summers, 1993). The authors provided participants in the study with a model of an observer and a horizon to use as a framework in which to describe the apparent motion of the sun, moon and stars. This allowed Mant and Summers to describe additional details about the participants’ understanding of apparent celestial motion beyond what was described in Sharp’s study.

The results of both Sharp (1996) and Mant and Summers (1993) will be discussed further in this section as I describe what these and other studies can tell us about children’s understanding of apparent celestial motion. Because these and most of the other studies available were conducted with participants older than the primary grade levels of interest for this dissertation (early elementary school) in many areas I will only be able to provide an general expectation of what children may know by upper elementary or middle school. Studies that have investigated early elementary children’s knowledge have dealt with the explanation for the day/night cycle and the shape of the earth. To create a picture of what we might expect students to believe about apparent celestial motion I will pull from literature dealing with elementary through adult subjects.
The most obvious aspect of apparent celestial motion is the daily rising and setting of the sun. Two studies show that even in late elementary school some children do not believe that the sun appears to move across the sky. In a study of 10- and 11-year-old children in England, Sharp (1996) found that nearly a quarter of the students interviewed (10 out of 42) were unaware of the sun’s apparent motion. A study of 11-year-old children in Italy also found that some students did not believe the sun appears to move (Viglietta, 1986). These studies suggest that because some older students have not developed an understanding of the apparent rising and setting of the sun that an even larger portion of early elementary students will be unable to describe this concept. However, Mant & Summers’ study of primary school teachers in England suggests that most people will be able to describe the motion of the sun as a path that moves across the sky by adulthood.

Children’s explanations for the disappearance of the sun at night may also help us explore their understanding of apparent celestial motion. The concept of rising and setting presupposes that the sun is somewhere “down” at night. However, some children explain this disappearance by claiming the sun has been covered by something such as the moon, the clouds, or “darkness” (Vosniadou & Brewer, 1994). Vosniadou and Brewer suggest that these explanations arise from children’s initial “mental models.” A mental model is a construct of the human mind, built from previously acquired knowledge and observations of the world that can be used to explain the world to others. Mental models can also be used to generate predictions and explanations. A child’s initial mental model is based only on his or her observations of the world. Thus, a child who has noticed other objects disappearing when they are covered by an intervening medium may also use this
explanation for the disappearance of the sun from the sky, removing the need to imagine the sun setting below the horizon. Vosniadou and Brewer found the use of the moon, clouds or darkness occluding the sun explanation was more commonly used among the first grade American students in their study, compared to the third and fifth grade students. Baxter (1989) interviewed a slightly older population of English students: 9 through 16 year olds. The concept that the moon covers the sun at night was used with about the same frequency across the age levels, but the concept that the clouds covers the sun at night decreased in frequency with older children. These studies suggest that some children may not describe the sun’s apparent motion as a path across the sky because they do not need to explain the sun’s appearance and disappearance by a rising and setting motion.

Studies of how children explain the day and night cycle also reveal that younger children are more likely to believe that the sun’s apparent motion is the same as its actual motion, rather than a result of the motion of the earth (Baxter, 1989; Jones, Lynch, & Reesink, 1987; Vosniadou & Brewer, 1994). Vosniadou and Brewer’s study of the day/night cycle found that many of the first grade students described the sun’s motion as going up and down while third and fifth grade students were more likely to say that the earth moves and not the sun to explain the day and night cycle. Baxter found a similar pattern with students in his study. Among the 9- and 10-year-old children interviewed, the most common response was that the earth goes around the sun once a day, followed by the idea that the sun goes around the earth, and then the scientific response of rotation. The 11 to 15 year-old students were more likely to use the scientific explanation. Jones, Lynch and Reesink’s comparison of third and sixth grade students’ knowledge of
astronomy also demonstrated that third grade students are more likely to use an earth-centered model than a sun-centered model compared to older children. Students who believe that the sun goes around the earth once a day may give the correct description of the apparent motion of the sun even though they have not yet learned to accurately explain that motion.

A common alternative idea about the path of the sun is the belief that the sun is directly overhead at noon (Brunsell & Marcks, 2005; Lightman & Sadler, 1993; Mant & Summers, 1993; Trumper, 2001a, 2001b, 2001c). In reality, this only occurs twice a year and only for people living in a band surrounding the equator (23.5 N latitude through 23.5 S latitude). Using a multiple choice questionnaire, Trumper (2001a) found that only 32% of the Israeli junior high students questioned answered correctly that the sun will never be directly overhead at noon at their location. This agrees with the results of Lightman and Sadler (1993), who surveyed over one thousand high school students on common astronomy concepts both before and after instruction. They found that approximately 8% of the students knew that the sun was never directly overhead before instruction and 18% after instruction. Mant and Summers (1993) also found that half of the 20 elementary school teachers in their study believe that the sun passes directly overhead at noon in England. The prevalence of this concept among middle and high school students as well as elementary school teachers suggests that many elementary children will also hold this alternative idea.

A complete understanding of the apparent motion of the sun also includes understanding how the pattern of motion changes across the seasons. Mant and Summers’ study of 20 elementary school teachers in England was the only study I located
that examined the change in the sun’s location and motion across the seasons. Seventy percent of the teachers knew that the sun’s altitude is higher in summer compared to winter but only 10% knew that the sun’s rising and setting positions change. This suggests that learning that the rising and setting position of the sun shifts is a more difficult concept to learn than the change in altitude. Thus we are less likely to find elementary students with this knowledge as well.

Children have more difficulty with the concept that the moon appears to move across the sky than the sun. In Sharp’s study of 10- and 11-year-old children, only 36% of the students were aware that the moon appears to move across the sky. Mant and Summers (1993) found a similar lack of understanding among the elementary school teachers. Only 10% indicated that they know that the moon follows the same apparent path across the sky as the sun and 30% were able to articulate that the moon does rise and set. The limited understanding of the apparent motion of the moon displayed by older elementary students and adults suggests that early elementary students are even less aware of the apparent motion of the moon.

Young children often associate the moon with the concept of night. Vosniadou and Brewer (1994) found that many elementary children describe the moon’s motion as opposite from the sun’s motion. Some children who described the moon’s motion as up and down “claimed that the moon moves in a “hydraulic” relation with the movement of the sun, that is, the moon goes down in the morning when the sun goes up, and later, when the sun goes down the moon goes up” (p. 156). This suggests that some students will only describe the moon as moving in the sky at night rather than the more complex pattern of motion actually exhibited by the moon. This is further supported by Sharp’s
interviews with 10- and 11-year-olds in which only 40% of the students had seen both the sun and moon in the sky together. Vosniadou and Brewer found that there was a shift from believing that the moon moves in first grade to believing that the moon is stationary in third and fifth grade. This was also observed for their understanding of the sun’s motion. While their investigation was designed to uncover children’s ideas about actual celestial motion, it may suggest that there will be a corresponding shift in how children describe the apparent motion of the moon between first and third grade.

By the end of elementary school, most children are likely to be at least aware of the changing appearance of the moon though they are less likely to understand the period of time for the change in the phase of the moon. Sharp (1996) found that all 42 of the 10- and 11-year-old students in his study were aware of several moon phases but the students gave a variety of answers to how long it takes for the moon to cycle through its phases. This is not surprising given that children and adults often have alternative ideas about the explanation for the phases of the moon and have difficulty learning the scientific explanation (Abell, Martini, & George, 2001; Baxter, 1996; Callison & Wright, 1993; Kavanagh, Agan, & Sneider, 2005; Stahly, Krockover, & Shepardson, 1999). Baxter (1996) found five frequently occurring ideas about what causes the phases of the moon among 9-16 year-old students: clouds, planets casting shadows, the shadow of the sun blocks our view, the shadow of the earth, and the scientific view. If early elementary students are basing their explanations and descriptions of astronomical phenomena on their initial mental models as Vosniadou and Brewer (1994) suggest, then younger children are more likely to use the concept that clouds are covering the moon to explain the phases because this relates to something they may have observed. They may be less
likely to use the ‘shadow of the earth or planet’ explanation because elementary children are still developing the concept of light and shadows (Guesne, 1985). Children who believe that the weather is involved in changing the appearance of the moon may think that the phases can change in less than a night rather than over an entire month.

The apparent motion of the stars is in many respects a more challenging concept to understand than either the motion of the sun and the moon. First, because there are stars in all directions, surrounding the earth, there are always stars in the sky, day and night. Second, the pattern of the stars in the sky remains fixed but also appears to slowly move across the sky throughout the night with new stars appearing over the eastern horizon and other stars setting in the west (except at the earth’s north and south poles). Many children and adults are unaware of the stars’ pattern of apparent motion. Of the 10- and 11-year-old students interviewed by Sharp (1996), only 14% were aware that the stars appear to move. Only 50% of Mant and Summers’ (1993) elementary school teachers were aware of the apparent motion of stars and far fewer (20%) were able to describe that motion. Given that younger children have had fewer opportunities to learn about the stars than the subjects of these studies, early elementary students are unlikely to know about the apparent motion of the stars at night.

Some of students’ difficulties with understanding the apparent motion of the stars may come from their lack of understanding of the exact nature and distance of the stars in combination with a lack of understanding of the effect of the rotation of the earth to our observations. Students in elementary school through high school have been found to hold many of the same alternative ideas about the nature of stars. Both Sharp’s (1996) study of 10- and 11-year-olds and Agan’s (2004) study of high school and college students
found that students are unclear about the composition or size of the stars. Both studies found students who believe that the stars are similar in size or smaller than planets: 50% of the high school students believe stars are smaller than planets and 50% of the elementary students believe that stars are smaller than the sun, earth and moon. Half of the high school students interviewed also believed that the stars are located near the planets. Without knowledge of the distance and size of stars, students may not appreciate the concept that the stars can remain as a fixed pattern from our perspective.

In a study of 12-year-old girls’ knowledge of astronomy on an open-ended exam, Dove (2002) found that while 78% of the students (N=98) were able to explain the apparent motion of a bright star across the sky with the rotation of the earth, nearly 22% of the students indicated that the star moved west to east rather than the same direction as the sun’s apparent motion (east to west). From this the author concludes “although most students are familiar with the idea that a spinning earth is responsible for the apparent migration of the sun across the sky during the day, they are unaware that this movement also explains the passage of stars across the night sky” (p. 830). It is unclear from Dove’s paper whether this is true, or if the students were merely confused on the direction of apparent celestial motion. However Dove’s conclusion does match previously mentioned studies (Mant & Summers, 1993; Sharp, 1996) which demonstrated that older students and adults are unaware of the stars’ apparent motion even when most subjects at that age are aware of the rotation of the earth and the apparent rising and setting of the sun.

Early elementary students are also more likely to believe the stars are not in the sky during the daytime. Vosniadou and Brewer (1994) found that only 15% of the first
grade students believe that the stars are still in the sky during the day while 45% of the third grade students and 60% of the fifth grade students understood this concept. This also appears to be a challenging concept for students to learn with school instruction.

Daikidoy and Kendeou (2001) compared two types of instruction on the day/night cycle and the shape of the earth with fifth grade students in Greece. The experimental instruction “took preconceptions into account, and … focused on explanations that would maximize the plausibility of scientific conceptions” (Daikidoy & Kendeou, 2001, p. 1) while the comparison (traditional) instruction did not. Even though the students in the experimental treatment significantly improved their understanding of the target concepts, nearly a third of the students (31%) did not believe that the stars remain in the sky during the daytime. However, the explanation of the stars’ daily disappearance was directly covered. Rather the instruction dealt primarily with how the earth’s rotation causes day and night. This supports the claim that instruction that only deals with the earth’s rotation and not all of the observable outcomes of that motion does not help students learn apparent celestial motion.

A related and perhaps integral part of children’s understanding of apparent celestial motion is their understanding of the concept of the sky. The word “sky” has both common everyday meanings as well as a scientific meaning, which may cause confusion in students trying to reconcile science instruction with their everyday understanding. This concept was largely ignored prior to Galili, Weizman and Cohen’s investigation of high school and college students’ mental models of the sky, visibility, and the moon illusion (2004). They found that many people associate the concept of sky with the atmosphere. This suggests that some students may have difficulties
understanding how the apparent motion of celestial objects in the sky relates to the actual motion and great distance of these celestial objects. Some people believe that the shape of the sky is related to the shape of the earth while others regard the profile of the sky to be flattened or oblate. These beliefs may influence how children describe the motion of celestial objects.

Vosniadou and Brewer’s (1992, 1994) assertion that children begin by creating mental models based on their observations of the world is supported by the students’ responses in their interviews. However, there is also evidence that students will only take those observations so far before they begin to rely on other sources of evidence for their explanations of the apparent motion of the sun, moon and stars. Viglietta (1986) claims the 11-year-old students in his study were not using their own observations as the basis for their responses. Rather, the students cited other authorities such as books or teachers. Sharp (1996) also found that most students quote secondary sources not their own observations to account for their descriptions of the appearance and shape of the sun. His study found that overall, students mentioned their own observations of celestial objects as a source only slightly more (31%) than secondary sources such as audio-visual (25%; video, TV, news, films), literature (14%; books, comics, newspapers, magazines, posters) and other sources such as teachers, planetarium visits, and computers (30%). Thus it may not simply be that students have not made the connections between their observations of the sun, moon and stars to the concepts of apparent celestial motion but rather that they are not making the observations of the sky that are needed to understand these patterns of motion.
Based on these previous studies of children’s knowledge of astronomy, we can make several predictions about what early elementary students may and may not know about apparent celestial motion. First, some students in early elementary school may not know or be able to describe the apparent rising and setting of the sun. This also suggests that children who do know the sun appears to rise and set will not have a fully accurate understanding of its path. Even fewer early elementary students are likely to understand that the moon follows the same path as the sun. Many that do believe the moon appears to move will believe this happens opposite of the sun’s motion, rising as the sun sets. Early elementary students are even less likely to understand the apparent motion of the stars. Many children believe that the stars are only in the sky during the night, and not the day, limiting their ability to understand the continuous rising and setting of the stars.

**Instructional design for apparent celestial motion**

The limited prior research on children and adult’s ideas about apparent celestial motion suggest that most are not making the types of observations necessary to understanding all of the complex patterns of motion. Therefore, the development and assessment of instructional techniques designed for these concepts is appropriate if we are to understand the support that students need to learn these concepts. Prior research in astronomy instruction has focused primarily on the explanations for observable astronomical phenomena (such as the day/night cycle, the phases of the moon and the seasons) and not on improving children’s understanding and ability to describe the daily, monthly, and yearly change to the day and night sky.
Instruction that is designed to improve students’ understanding of apparent celestial motion requires careful consideration of the challenges posed by this particular subject matter. These challenges include:

- Children have limited experience making observations of the change in location of the sun, moon and stars.
- The apparent motion occurs so slowly that it is unperceivable by a single direct observation.
- It is difficult to accurately represent the appearance of objects in the three-dimensional sky.

I have chosen to investigate children’s abilities to learn about apparent celestial motion in a setting designed to mimic the real sky (the planetarium) using kinesthetic learning techniques designed to support and scaffold the students’ abilities to learn these specific concepts. In this section, I will describe how conceptual change theory has influenced the design of the instruction for this study as well as other research that support the use of kinesthetic learning techniques and the planetarium in astronomy instruction.

**The constructivist process of conceptual change**

In the past many educators believed that young children approached learning as blank slates, ready to learn the concepts just as they were presented. It is now recognized that all learners have prior conceptions of the world that mediate the acquisition of new ideas. Students come to any learning situation with their own ideas about the world based on their experience with the world, both in and out of the classroom. One way to explain the process of learning science is through the theory of conceptual change, a constructivist process by which the existing knowledge structure can be built upon through the assimilation of new ideas or more radically reorganized to accommodate new information (Posner, Strike, Hewson, & Gertzog, 1982). A key factor in the success of
conceptual change is a learner’s prior knowledge. Pintrich, Marx, & Boyle (1993) suggest that prior knowledge presents a paradox to the process of conceptual change. Prior knowledge can hamper conceptual change when the new concepts do not align with the learner’s framework of beliefs and prior knowledge of the world. A student may interpret new concepts in a way other than was intended or the student may reject the new concept in favor of their current understanding of the world. Yet prior knowledge is also necessary to help facilitate the incorporation of new ideas. Another way of examining this paradox is to consider that “the conceptual change model would suggest that students who possess little prior knowledge in an area would have few barriers to learning new concepts, yet the literature on learning shows clearly the value of prior knowledge” (Pintrich, Marx, & Boyle, 1993; p. 191). The paradoxical role that prior knowledge plays in conceptual change suggests that care must be taken in designing instruction.

Students do not merely need to learn the scientific concepts; they need to accept those descriptions of the world in favor of their current ideas. Conceptual change theory suggests that in order for a student to reject their previous understanding of a concept, the learner must not only be dissatisfied with their current understanding but they must also be provided with a new idea that fits into other aspects of how they understand the world (Pintrich et al., 1993; Posner et al., 1982; Strike & Posner, 1990). Strike and Posner (1992) also suggest that motives, goals, and the social context are important factors in the process of conceptual change. In other words, conceptual change requires that a student is sufficiently engaged for the necessary processing to occur. Depth of processing and engagement are related to a student’s motivational factors such as their level of interest and feelings of efficacy with respect the concepts (Pintritch et al., 1993).
Much of the research into children’s understanding of science has described how a child’s view of the world is inaccurate or alternative to the scientific perspective. Some of these ideas are based only on a child’s initial observations of the world. Others may be the result of conceptual change in a science learning environment that did not result in the scientific view. I will refer to these concepts as “alternative ideas” as they are alternatives to the scientific view. These concepts are also known as misconceptions in the literature, a term that denotes a “mistake” in the student’s knowledge. This negative connotation may not be appropriate because these ideas are often based on learners’ observations of the world and can be steps along the way towards the scientific understanding, given appropriate instruction.

While some alternative ideas may be firmly entrenched in a student’s understanding of the world, this is not necessarily the only form they may take. First, alternative ideas may exist as only “images” or “body language” of how something works (Strike & Posner, 1990, p. 6). For example, a child may only have an image in mind of the sun going up and down in the sky rather than a fully developed theory about this motion. Second, alternative ideas may only be developed when a student is first asked to answer a new problem. They are generated on-the-spot from the students’ prior knowledge of the world. For example, the child who believes that the sun moves up and down during the day may have never considered where the sun is at night. When asked, the child may extend their description of the sun’s motion to say it is “down”, or behind a hill, or even that it is covered by clouds at night if they have observed the clouds covering the sun during the day. It is therefore important to consider the knowledge framework
that students use to create new ideas and explanations to understand the full nature of alternative ideas.

**Conceptual change informing instructional strategies**

Conceptual change theory can be used to make decisions about the kinds of instructional strategies that will be most successful. First, instruction that is successful in changing students’ alternative ideas considers students’ prior knowledge and attitudes toward the subject. From this perspective, instruction is designed that starts at an appropriate place with regards to the students’ current view of the world. This can be done in general based on prior assessment of a similar group of students as well as by assessing individual students. Children are likely to lack the observational experiences needed to build an understanding of the pattern of change in the sky. Some of the challenges these students’ face in learning apparent celestial motion from their limited experiences with observing and describing these phenomena may be countered by providing a rich, experiential environment in instruction. In this section I will describe some ways that conceptual change theories have influenced the instructional design of Study B (learning apparent celestial motion in the planetarium).

One method discussed in the literature that may promote conceptual change is the use of cognitive conflict and resolution (Scott, Asoko, & Driver, 1991). In this model, conceptual change is considered to be the active reorganization of existing knowledge to accommodate new ideas. Instructional strategies for cognitive conflict begin with the students’ activating their prior knowledge through engagement with an event or discussion and then expose students to a discrepant event. As suggested previously, it is not enough that the student notice the discrepant event. “[A]lternative ideas have to be
offered and these need to be seen by students not only as necessary but also reasonable and plausible” (Driver, Guesne, & Tiberghien, 1985, p. 6). Therefore, in the cognitive conflict model, instruction attempts to provide guidance in the accommodation of the new concept into the existing mental model. An alternative form of cognitive conflict instruction engages students in debate of different ideas about the same concept. The source of these ideas would include the students’ ideas and the scientific model presented by the teacher.

In the case of celestial motion, the students will have alternative ideas about the apparent motion of the sun, moon and stars. The “discrepant events” used in the cognitive conflict model are the scientifically accurate demonstrations of apparent celestial motion coupled with verbal descriptions to help students interpret their observations of the phenomena. The challenges presented by the use of the cognitive conflict model are a) how to help the student to recall their prior knowledge of celestial motion, b) how to present the accurate description of that motion and c) how to allow the students to engage in comparing the “discrepant” description with their initial understanding.

The setting used for instruction is one way that may help children engage in the concepts of apparent celestial motion. A key feature of the planetarium is how it can be used to help students visualize new representations of celestial phenomena. As mentioned previously, one of the major challenges that students face in learning about celestial motion is their lack of experience with observing or describing these phenomena. An important aspect of children’s knowledge of celestial motion is the visual representations they associate with this topic. The planetarium allows us to show
images of celestial objects as they would appear in the sky and then manipulate them to show their motion through time. However, because the instruction used in this study only takes place in the planetarium and does not include first-hand experiences with the actual phenomena described (such as actually tracking the position of the moon), it may be limited in it’s power to change the students’ belief. The students must accept that the model demonstrated in the planetarium program is an accurate representation of the real sky and motions.

Previous research on the relationship between verbal information and imagery has demonstrated the powerful importance for how we understand learning and how students make connections between concepts and images and is potentially useful in understanding the benefit of instruction in the planetarium. The Dual Coding Theory (DCT) suggests that human behavior and experience can be explained “in terms of dynamic associative processes that operate on a rich network of modality-specific verbal and nonverbal (or imagery) representations” (Clark & Paivio, 1991, p. 149). Both the verbal and nonverbal systems consist of separate subsystems, capable of functioning independently (Paivio, 1986). The nonverbal system’s subsystems correspond to different sensory modalities, such as visual, auditory, and haptic or kinesthetic. These different subsystems then form an integrated whole by the connections between these subsystems. Thus we may understand a ball in terms of the verbal description of its shape, the visual image of the ball as we turn it around, and the haptic sensation of the smooth continuous feel of the ball when we hold it. We can access each of these mental representations separately or in concert. Paivio suggests that because these different modalities exist in interconnected subsystems “processing can be switched from one
system to another under appropriate conditions” (p. 58). The connections that link verbal and nonverbal representations in a complex association may allow words to trigger potentially more complex and useful nonverbal mental representations. “Active mental representations can in turn activate associatively related nodes in the network, and this spreading activation results in complex patterns of arousal among the representations in the network” (p. 154).

According to DCT, “nonverbal representations can encode information in parallel or simultaneously” (Clark & Paivio, 1991, p. 152), unlike verbal processing which occurs in a sequential fashion. Simultaneous encoding allows nonverbal representations to contain much more complex and detailed information. This is related to another difference between the verbal and nonverbal systems; the way that we understand the world through imagery is continuous in nature, rather than relationships between discrete items (Paivio, 1986). This allows us to do useful operations on mental images such as performing spatial transformations, such as turning a ball around in one’s mind, that are not possible with verbal representations. Such complex operations are extremely useful in the field of celestial motion.

A great deal of what is important in apparent celestial motion is tied to the mental images of what it means for the sun to rise and set or the appearance of the moon to change. Therefore, instruction that builds up children’s repertoire mental representations in the visual mode may help them develop a full understanding of apparent celestial motion. This way of understanding the verbal and nonverbal symbolic systems also suggests that successful instruction helps students form the structural connections between various verbal and nonverbal representations such that students can trigger the
appropriate mental representation (whether it is verbal, auditory, kinesthetic) for future related activities. Clark and Paivio suggest that “students and others are more likely to generate mental images if instructed to do so than if left to their own devices. Such imagery instructions are incorporated into various memory techniques that facilitate vocabulary and other school learning” (1991, p. 155). Children interacting with the imagery displayed in a planetarium are exposed to an opportunity to make new connections in their knowledge structure using images of celestial motion and connecting those images to such verbal code as ‘the rising and setting of the sun’ or ‘the apparent motion of the stars during the night.’

Conceptual change theory also suggests that instruction that actively engages students in comparing the new ideas presented to their current concepts may facilitate conceptual change. This piece of active engagement is critical to either simple assimilation of a new but compatible idea, or a more extensive restructuring of existing ideas. Students are likely to either ignore or misunderstand information that is received verbally if their prior knowledge of the topics is not aligned with the new ideas (Strike & Posner, 1990). In the 1970s, the planetarium community began to discuss how to actively engage the audience in the program rather than the traditional, more passive, model. This resulted in the creation of ‘participatory planetarium programs’ (Friedman, Schatz, & Sneider, 1976).

In 1982, Mallon and Bruce investigated the use of participatory planetarium programs in small educational planetariums. Through a paper-and-pencil content test and a Likert-style science opinionnaire, they found that the participatory oriented program is more effective in teaching constellations, and possibly for improving students’ attitude
towards astronomy. Bishop (1980) investigated the achievement of eighth grade students using individual and oral tests resulting from different participatory planetarium methods. The participatory methods used in this study had the students manipulating models and drawing pictures of their perceptions of the sky. Bishop found that model manipulation and drawing in the planetarium can help students learn projective astronomy concepts (such as day-and-night, the phases of the moon). Beyond these studies, there has been little published research investigating the use and educational value of participatory planetarium programs.

The present study investigates the success of a planetarium program that encourages students to participate through the use of kinesthetic learning techniques (KLTs). KLTs are designed to actively engage in developing knowledge of specific concepts by having students use the motion of their own bodies. However, research on the use of KLTs to improve understanding is limited. I will make the case that KLTs can be used in ways that are consistent with instruction designed to promote conceptual change by actively engaging the students with body and mind and helping students’ access their prior knowledge.

KLTs are designed to follow and mimic the paths of celestial objects. This provides a means of engaging all of the students, regardless of their ability to articulate their ideas. Students who are engaged in mimicking the motion they are observing are clearly processing what they are observing at some level. The importance of this processing can be explained by Dual Coding Theory (DCT). According to Clark and Paivio (1991):

…DCT conceptualizes motor skills in terms of images for perceptual patterns and movements, relevant verbal codes, and associative and referential processes that
govern activation of the interconnected codes… Nonverbal components of the motor system include both kinesthetic and visual images. Kinesthetic imagery refers to the “feel” of the action from an internal perspective. (p. 185)

First, this suggests that some of the power of kinesthetic learning may lie in connecting kinesthetic imagery to the verbal and visual codes for that subject. Through the use of KLTs, students can build their vocabulary of kinesthetic images that may help them describe apparent celestial motion and use these concepts in future problem-solving scenarios. By studying these concepts in the planetarium, the students are learning these representations simultaneously and thus forming a network of connected mental imagery and verbal codes that may be accessed at a later time. Second, DCT suggests that each system undergoes separate processing. Thus we are forming ways of understanding new phenomenon in each subsystem that responds to the stimulus. Instruction that is designed to take advantage of the processing of different modalities may help students because the new “ideas” will be coded in multiple ways.

This idea of building support for future problem solving is supported by research on the use of gesture to represent ideas. Many people naturally gesture as they talk or reason out problems. Gesture research suggests “the first step a learner takes in acquiring a concept appears to be reflected in gesture” (Alibali & Goldin-Meadows, 1993, p. 511). Additional research has shown that students use gesture to help them in novel problem solving situations (Crowder, 1996). Experience in gesturing as part of learning about celestial motion may provide the students with cognitive tools for future conceptual change through the use of gesture in problem solving.

Kinesthetic learning techniques can also be used to activate prior knowledge through motions that are designed to make predictions before the scientific concept is
introduced. Some children who are unable to fully articulate their ideas verbally may still have an understanding that could be expressed through their own gestures. Following this step, kinesthetic learning techniques can produce cognitive conflict when the motion the students demonstrate do not match the motion they initially described. The conflict will then potentially motivate the learners to actively compare their prior ideas to the new description and imagery of the problem. What happens next may depend on the depth of engagement and how the new model of motion compares to the students’ current understanding of the world. If the motions that the learner has performed and observed are found to be a useful description of the world then the learner may assimilate this description and its corresponding kinesthetic and visual images into their knowledge framework.

Druyan (1997) described experiments investigating kinesthetic-cognitive conflict – bodily experience that contradicts cognition. Her investigation of children using kinesthetic-cognitive conflict to learn concepts of length, balance, and speed show that kinesthetic conflict can be more effective in promoting scientific reasoning in young children compared to visual or social methods. Druyan (2001) also conducted a study of cognitive conflict involving preschool children, third, and fifth grade students solving balance problems. Kinesthetic conflict was found to be the most effective for preschool children, where as social conflicts were more effective with older children (however, social conflict models would be difficult to enact in the typical planetarium environment). Druyan (1997) argues that the “conscious conflict between the erroneous concept and the kinesthetic information appropriate for the scientific concept is created on the level of basic cognitive processes, and the need for its reconciliation enabled reconstruction of the
concept” (p. 1097). She goes on to speculate as to whether the benefits of kinesthetic conflict (over simply the visual conflict) are due to double feedback of both kinesthetic and visual information or the existence of separate processing of kinesthetic information. She also points to dual coding theory, suggesting that this aspect of double feedback is playing a role because the learners are encoding the information as a kinesthetic image as well as a visual image (Clark & Paivio, 1991; Paivio, 1986).

Astronomy learning experiences using kinesthetic techniques have been developed for grades 6 through adults by Cherilynn Morrow (2000). The lessons allow the students to experience kinesthetically the motion of the earth that results in the sun and stars rising in the east, the change in altitude of the sun over the year, the seasonal change of the stars, and other topics. Field-testing of these activities suggests that these kinesthetic astronomy techniques “allow learners to achieve a good intuitive grasp of concepts that are much more difficult to learn in more conventional ways” (introduction page; Morrow and Zawaski, 2004). However, there have been no published studies on this work to support the use of KLT using this curriculum.

Consistency and coherence in children’s ideas of science

Another way of examining students’ understanding of apparent celestial motion is to consider whether or not students exhibit an internally consistent and coherent knowledge structure of these patterns of motion. Understanding how children organize their knowledge of astronomy may help us design successful instruction because we will be able to address the structure of children’s understanding and not just individual elements. Driver, Guesne, and Tiberghien (1985) argue that students’ ideas do not always seem to form a coherent framework, at least compared to a scientific perspective,
because students do not perceive the same need for coherence as scientists. Instead, students often find that their individual schemas work well for narrow settings. Vosniadou (2002b) argues that young children have a natural tendency towards coherent structure and that inconsistencies are a result of attempts to accommodate scientific ideas. diSessa (diSessa, 1993; diSessa, Gillespie, & Esterly, 2004) suggests that the lack of coherence is a by-product of fragmented system of knowledge. Vosniadou and diSessa’s models argue for alternative ways of understanding knowledge and conceptual change. Recent papers by both authors have attempted to analyze both models and give evidence for the validity of their own model of knowledge development (diSessa, 2002; diSessa, et al., 2004; Vosniadou, 2002b; Ioannides & Vosniadou, 2002). In this section I will describe both Vosniadou and diSessa’s models, followed by a discussion of how this may apply to understanding children’s knowledge of apparent celestial motion.

Vosniadou and her colleagues’ include in their theory of conceptual change (Vosniadou & Brewer, 1994; Vosniadou, Ioannidis, Dimitrakopoulou, & Papademetriou, 2001; Vosniadou, 2002a; 2002b) a theory of naïve physics that allows children, from infancy, to make sense of the world. Children develop initial, domain-specific presuppositions about the world through their experiences and use this as a way to interpret and assimilate new experiences. Vosniadou et al. (2001) suggest that “explanations of physical phenomena often violate fundamental principles of intuitive physics, which are confirmed by our everyday experience. For this reason learning science requires the radical reorganization of existing conceptual structures and not just their enrichment, and the creation of new, qualitatively different representations” (p. 3). There is a large resistance to change because these ideas are integrated with other
concepts. Changing one idea potentially requires the alteration of many other concepts and structural connections.

Underlying this theory of naïve physics is the supposition that children develop domain-specific theories (“a coherent body of knowledge that involves causal, explanatory understanding” (Vosniadou, 2002a, p. 2)) from their initial presuppositions, that eventually become embedded within a larger framework theory about how the world works (Vosniadou 2002a, 2002b; Vosniadou & Brewer, 1994). For this reason, Vosniadou’s view is also known as the Framework Theory model. Vosniadou differentiates the theories of children from scientific theories in that they “lack the systematicity” and differ “both in terms of the representations and in terms of the cognitive mechanisms they use” (Ioannides & Vosniadou, 2002, p. 4). This provides the basis from which mental models are constructed. Naïve mental models are cognitive representations of the world that preserve the basic characteristics of the phenomena or objects they represent. More importantly, “they can be explored extensively, run in the mind’s eye, so to speak, in order to generate predictions and explanations” (Vosniadou, 2002a, p.4). From this we can derive the important function of mental models – they influence how learners interpret new information about the world as well as allowing them to construct new explanations when prompted. Thus alternative ideas, or misconceptions, are not “mistakes.” Rather, they are integral parts of the organized “mental models” held by the learner.

In the Vosniadou view of conceptual change, students are capable of and naturally move towards coherence within their mental models of specific phenomena, such as the shape of the earth (Vosniadou & Brewer, 1992), the day/night cycle (Vosniadou &
Brewer, 1994) or the concept of force (Ioannides & Vosniadou, 2002). Children organize what they learn about the world in a coherent system or framework in their attempt to make sense of the world. This may involve both adding information to specific theories as well as more substantial restructuring. Because restructuring is a much more involved and difficult process, children are more likely to simply assimilate aspects of science into their specific theories and framework without altering presuppositions that may be in conflict. When this happens, the overall framework looses coherence as well as produces new alternative ideas or “synthetic models.” A synthetic model is a combination of naïve theories of the world based on observations and aspects of a scientifically accurate concept (Vosniadou & Brewer, 1994).

An alternative theory of naïve physics is founded on the analysis of individual elements of knowledge (diSessa 1988, 1993). In this view, initial knowledge structures of intuitive physics consist “substantially of hundreds or thousands of inarticulate explanatory primitives, which are activated in specific contexts and, as a whole, exhibit some broad systematicity, but are not deeply systematic enough to be productively described individually or collectively as a theory” (diSessa, et al., 2004, p. 846). The basic elements, the phenomenological primitives (p-prims), are created from experiences and interpretation of the real world and can be evoked to help explain future interactions with phenomena. This also explains the formation of alternative ideas. The development of connections between various p-prims may not result in the scientifically accurate view.

Thus learning involves developing a system to activate the correct p-prims for appropriate situation. In diSessa’s view, knowledge is a complex system:

The naïve state consists of a large number of conceptual elements of varying types. Those elements are modified and combined in complex ways, possibly in
levels and into subsystems that, together, constitute the “final” configuration of an expert concept (diSessa, 2002; p. 30).

The resulting large, complex systems, made up of p-prim elements, are termed “coordination classes.” The purpose of the coordination class is to determine information from the world that is not immediately obvious. These are complex to achieve, and thus not expected to be found in novice learners. Time and effort on the part of the learner are required in order to reach the level of “coordination” necessary to have the expert understanding of a conceptual area.

This theory of Knowledge in Pieces, or Fragmentation, stands in sharp contrast to Vosniadou’s work which describes knowledge as a natural trend toward coherence and existing in an over-arching framework theory. While there are similarities and agreements in the models, there are also important differences that influence how we interpret conceptual change and plan instruction in science. Agreement comes in terms of some of the basic elements of knowledge, such as Vosniadou’s statement:

We believe that p-prims can be interpreted to refer to the multiplicity of perceptual and sensory experiences that are obtained through our observations of physical objects and our interactions with them. In the conceptual system we propose, diSessa’s p-prims would take the place of the perceptual information obtained through observation. These perceptual experiences provide the basis for forming beliefs, presuppositions, and mental models (2002b, p. 65).

The primary differences between these two theories are their view of the developmental aspects of knowledge and how the knowledge structure should be viewed as a whole.

The fragmentation view of knowledge predicts that students’ initial understanding of science, based on their observations of the world, exists largely unstructured and without the rich internal coherence predicted by the Framework Theory model. diSessa (1993) describes the process of understanding as “a gradual sorting of ideas to build an
abstract explanatory framework, albeit one with some fairly dramatic limitations of systematicity” (1993; p. 196). This view also places a much greater importance on contextualization. Because there is no overarching framework to specify how an individual will interpret every circumstance, context plays a large role in what meaning the learner takes from the situation. Likewise, conceptual change will naturally be more specifically context-limited. Conceptual change can be viewed then in terms of a localizable event, which takes place over a few concepts and not a larger framework. It is a process of connecting together, or systematizing, the knowledge fragments and aligning those p-prims towards more complete structures (diSessa, 1993).

Vosniadou’s Framework Theory model predicts that children’s knowledge begins in a state of coherence: a learner will interpret and make predictions about phenomena and situations that are consistent with one overall “theory” that describes the world. But on the way towards the development of a scientifically accepted view of the world, the learner encounters ideas that are not consistent with their coherent framework or specific theories. It is through the process of assimilating the new “scientific” ideas that the learner’s mental model becomes incoherent.

**Conceptual change theory and celestial motion**

The theories of knowledge structure and conceptual change described above play a role in both interpreting children’s knowledge of apparent celestial motion as well as how we may predict instruction will impact that understanding. Vosniadou’s Framework Theory suggests that children will describe apparent celestial motion according to a coherent interpretation of their own specific theories pertaining to celestial objects, the earth, and motion. In her work describing children’s mental models of the day/night
cycle, she suggests that most young children can be placed in one of a few types of coherent mental models (Vosniadou & Brewer, 1994). The children’s answers to questions about the causes and consequences of day and night are the direct result of these coherent models. In this view, children’s descriptions of apparent celestial motion should be consistent with one of these mental models, because the motion is ascribed by the overall framework theory that governs celestial objects. Any inconsistencies in children’s answers would be interpreted as the result of improperly assimilated “scientific” ideas learned in school or other culturally relevant venues within the learner’s mental model.

Vosniadou’s theory implies that children will be resistant to changing their ideas about apparent celestial motion because these ideas are the result of structured and coherent mental models. Attempting to change a child’s concept of one aspect of apparent motion, such as the path of the moon, may require addressing all of the underlying presuppositions that resulted in the child’s framework theory. This would suggest that instruction should address more than just the child’s ideas about apparent celestial motion; it should also address their ideas about the actual motion.

diSessa’s Knowledge in Pieces theory predicts that the students will have elements of knowledge relating to various aspects of the expert view of apparent celestial motion. diSessa suggests that there is not a direct one-to-one correlation between the student’s initial concepts of a phenomena and the expert’s concept. Rather, the organization of many different types of knowledge in the novice will be very different than how the expert understands the concept. In terms of understanding of celestial motion, children do not have the same level of systematic organization of the key
concepts that an expert would use to understand celestial motion. If we use the term p-prims to describe basic elements that students use to interpret and describe their ideas of the sun’s apparent motion across the sky, the students may be associating various p-prims for how things move and how things appear in ways that do not actually match the reality of the sun’s curved path across the southern sky.

Another consequence of the fragmentation perspective is that we would not expect to see a straightforward connection between a child’s naïve description of the motion of the sun, moon and stars, and their description of the shape of the earth or the cause of day and night. If these various elements of astronomy knowledge are not the result of a framework theory, then students’ answers are more likely to be pulled from a more localized connection of elements relating to observations and ideas about the world. Children’s knowledge may “exhibit some broad systematicity” but this is more contextually connected and not at the level that would be as powerful as a theory (diSessa, 2004).

However, diSessa (2004) points out that the “Knowledge in Pieces perspective was developed specifically to deal with experientially rich domains, such as mechanics. Application to other domains is at least somewhat speculative, and possibly even doubtful, without that inherent richness. Thus, results outside mechanics favoring the coherence view, including earlier work by Vosniadou, are not immediately threatened…” (p. 888). For this reason, we need to consider how lack of prior experience with observations of these types of motions and thought about these celestial objects plays a part in the nature of the students’ naïve understanding, and the nature of the conceptual change that may occur. Children’s beliefs about celestial motion can be tied to their
beliefs about the properties of celestial objects as well as the nature of the earth. Children have a much richer experiential base to work from with regards to the nature of the earth compared to the properties of the sun, moon and stars.

The instruction that was designed for this study, in the setting of the planetarium program, was only designed to address students’ ability to describe the patterns of celestial motion and not their beliefs about why these objects exhibit patterns of motion (though care was taken to use the accurate scientific language in describing what the students were observing). This decision was based on the assumption that children do not have a rich enough theory of the relationship between the sun, earth, moon and stars to make predictions about motion just based on theory. I have also based this on the belief that children have assumptions about motion that are more contextual-based, tied to specific celestial objects rather than to a larger framework. This study examined whether or not children’s ability to describe the patterns of celestial motion can be improved through instruction that does not specifically address other related aspects of knowledge (such as the shape of the earth or the underlying explanation for cause of motion). The perspective outlined above aligns this work more closely with diSessa’s Pieces of Knowledge theory than Vosniadou’s Framework Theory model.

**Chapter Summary and Implications for this Study**

In this chapter I began by outlining the relevant literature pertaining to research on children’s ideas of celestial motion. This review of the astronomy education literature reveals that there is still much to be learned about what children believe about the patterns of motion of celestial objects from an earth-based perspective. Students’ ideas about heliocentric motion and explanations of the day/night cycle suggest that young
children will have a variety of ideas about the motion (or lack of motion) of the sun, moon and stars, but does not reveal children’s concepts or abilities to describe these patterns of motion nor does it give us an understanding of a possible progression of these ideas across different age groups. However, we can expect to see many alternative ideas emerge through interviews with students, either based on their attempts to describe their own observations of the world or to reconcile scientific concepts with their own “naïve” views. For this reason, the first half of this dissertation will focus on analyzing elementary and middle school students’ ideas about the patterns of apparent celestial motion.

Second, I have proposed a method for improving children’s knowledge of celestial motion that uses kinesthetic learning techniques as an instructional strategy set in the rich visual environment of the planetarium. The power of this strategy lies in its ability to engage all students in a way that is relevant to the subject – apparent motion. It also provides the children with a cognitive tool to use in describing and thinking about celestial motion. In the setting of a planetarium program on apparent celestial motion, students can compare differences in their initial models to the scientific model and through cognitive conflict change their understanding. The success of using this technique in the topic of astronomy or in other areas of science has not been previously tested. Thus the results of this study will add to our knowledge of successful instructional strategies for astronomy and potentially other domains as well.

Finally, this review has outlined current theories of conceptual change in order to suggest some relevant strategies for both understanding the progression of children’s ideas about celestial motion and helping students move towards a scientific description of
these phenomena. And while there is some broad agreement on certain aspects of conceptual change theory that will be useful in this study, there are also areas of contention in the theory as it relates to the very core of what is happening cognitively. The instructional strategies designed for this study assumes a more fragmented model of children’s understanding of apparent celestial motion that is not part of a more tightly held coherent framework of understanding.
CHAPTER 3
METHODOLOGY

Overview

This chapter will address the methodology used in the two related studies described in this dissertation. The purpose of Study A is to first assess and describe children’s prior knowledge concerning the patterns of motion of the sun, moon and stars, and second, to examine whether or not children’s understanding about these concepts changes from early elementary through middle school, through a cross-sectional study. In order to capture the children’s ideas in detail, I used a small dome to represent the sky in the interviews. The analyses of these topics were guided by following research questions:

1. What are students’ conceptions of the patterns of motion of the sun, moon, and stars, as viewed from the earth?
2. Do students’ conceptions of the motion of the sun, moon, and stars change with age?

The purpose of the second part of this dissertation (Study B) is to determine whether students demonstrate improved understanding of the topics assessed in Study A after attending a planetarium program on celestial motion that uses kinesthetic learning techniques. Students in first and second grade were interviewed before and after the planetarium program using the same interview protocol and coding procedure as was used with the students in Study A. Analysis of the results of these interviews was guided by the following research questions:
1. Do students who participate in a planetarium program improve their knowledge of the patterns of motion of celestial objects by using kinesthetic learning techniques (KLTs)?
2. Did students learn about addition topics covered in the planetarium program that were not part of instruction using kinesthetic motion?
3. Did students explanations for the disappearance of the sun and moon from the sky change as a result of the planetarium program?

This chapter will describe the students who were interviewed for both studies, the interview protocol and setting, and the methods used to analyze the data collected.

Participants

Study A

The children interviewed for Study A were in first, third and eighth grade. The range was chosen to look for changes across the early elementary years, the level that the National Science Education Standards (NSES; NRC, 1996) suggest the students should be learning these topics, and then compare this to how these ideas are expressed by middle school students. Astronomy is not a common subject studied after eighth grade. For that reason, general knowledge of the patterns of celestial motion may be relatively constant after middle school, unless the learner has additional out-of-school experiences that influence their understanding.

The first and eighth grade classes were selected by contacting teachers who had visited the natural history museum where the planetarium used in Study B is located. The first grade class attended Adventure Elementary School for kindergarten through sixth grade in a small Midwestern town. The principal at Adventure found a third grade teacher who agreed to let me interview her students. The eighth grade students attended

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3 All names of persons, institutions and locations are pseudonyms.
Pekin Middle School for sixth through eighth grade students in another small Midwestern town. Students in each grade were selected by choosing the first ten girls and ten boys who had returned permission letters and were available to be interviewed at that time (except for the first grade group where less than ten boys had completed permission letters). Children were interviewed in their schools during normal class time.

A total of sixty students from first, third, and eighth grade were interviewed for this study. The third and eighth grade groups were evenly split by gender. The first grade group was comprised of 8 boys and 12 girls. The mean age of the first grade students\(^4\) was 6.6 years (SD = 0.3). The mean age of the third grade students\(^5\) was 8.7 years (SD = 0.3). The mean age of the eighth grade students was 13.8 years (SD = 0.4). Students in the first grade class were interviewed December 9 and 10, 2004. Students in the eighth grade class were interviewed December 14 and 15, 2004. Students in the third grade class were interviewed January 10 and 12, 2005.

**Study B**

Eight teachers of first and second grade agreed to allow their students to participate in the Study B. Five classes were a combination of first and second grade students from Allensville Elementary school in a small Midwestern city containing a university. The other three classes were second grade students from Adventure Elementary School. One of the five combined first and second grade classes was chosen to pilot the interview and planetarium process. After this program, the teacher made suggestions about what she observed. She suggested that more emphasis be placed on

\(^4\) Three of the first grade students did not know their date of birth. I did not ask one student her age (N=16).
\(^5\) One third grade student did not know his date of birth (N=19).
describing the apparent motion in terms of the rotation of the earth. These suggestions were incorporated into the final program. There were also improvements made to the delivery of the content and organization of the program. I felt that the changes to the program after the pilot testing were significant enough to drop this class from the final analysis.

From the other seven classes, I randomly selected or allowed the teacher to select (chosen for a range in abilities) five girls and five boys from the students with parental permission to participate in the study. In total, 63 students were interviewed before and after the planetarium visit. Attrition occurred because some students did not attend the planetarium show, were not in school when the post-interviews were conducted, or in one case, choose not to be interviewed again. Sixteen students were in first grade (7 female, 9 male). Forty-seven students were in second grade (23 female, 24 male). Overall, 30 students were female and 33 were male. Students ranged in age from 6.4 to 8.8 years old with an average age of 7.6 years.

**Data collection**

In this section I will first describe how the interview protocol and setting were developed through pilot testing. The setting was chosen to best capture the students’ understanding of apparent celestial motion in a detailed and open-ended manner. The interview questions and how they relate to the overall goal of describing students’ understanding of celestial motion are discussed. Finally, I will describe the changes made to the interview protocol for Study B.

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6 A first grade girl did not want to be interviewed again. She did not give a reason.
Development of the interview and pilot testing

The topics covered in the interview were selected primarily based on the astronomy topics found in National Science Education Standards and the Benchmarks for Science Literacy (Benchmarks; AAAS, 1993) for early elementary grades (see Table 3.1). All of these topics address the motion of the sun, moon and stars as they appear from the earth’s surface. They do not cover the explanation for apparent celestial motion such as the rotation of the earth, the orbit of the earth around the sun, and the orbit of the moon.

Table 3.1 Standards and Benchmarks for apparent celestial motion and change

<table>
<thead>
<tr>
<th>National Science Education Standards</th>
<th>Benchmarks for Science Literacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content Standard D: Earth and Space Science</td>
<td>Chapter 4A: The Universe</td>
</tr>
<tr>
<td>Grades K-4 The sun, moon, stars, clouds, birds, and airplanes all have properties, locations, and movements that can be observed and described.</td>
<td>Grades K-2 The sun can be seen only in the daytime, but the moon can be seen sometimes at night and sometimes during the day. The sun, moon and stars all appear to move slowly across the sky.</td>
</tr>
<tr>
<td>Objects in the sky have patterns of movement. The sun, for example, appears to move across the sky in the same way every day, but its path changes slowly over the seasons. The moon moves across the sky on a daily basis much like the sun. The observable shape of the moon changes from day to day in a cycle that lasts about a month. (p. 134)</td>
<td>The moon looks a little different every day, but looks the same again about every four weeks. (p. 62)</td>
</tr>
<tr>
<td>Grades 3-5 The pattern of stars in the sky stay the same, although they appear to move across the sky nightly, and different stars can be seen in different seasons. (p. 63)</td>
<td></td>
</tr>
</tbody>
</table>

I began each interview by prompting the students to tell me about the types of activities they like to do outside during the summer and then, later in the interview, the winter. This was done in order to help the students to bring up their own personal experiences and allow them to think about situations where they might have observed the
sun. The flow of the interview covered the sun, then the moon and then the stars followed by a few more questions about day and night. First, we discussed the apparent motion of the sun in summer followed by the sun in winter. Then I asked the students to think about whether or not the sun in the real sky outside is actually moving at that moment. We transitioned into talking about the apparent change in appearance of the moon followed by the apparent path of the moon across the sky. This was followed by questions about the apparent movement of the stars. We finished by talking about where the sun would be at night and what would happen to make it day again. This progression allowed the students to first talk about more familiar and then gradually less familiar concepts through the interview. This sequence will be discussed in more detail below.

In developing the interview protocol, I was concerned about the setting in which the students would answer the questions and how they would provide their responses. Because these questions dealt with three-dimensional motion across the sky, I doubted the validity of the results if they were asked to translate a three-dimensional concept to a verbal response or a two-dimensional image response (such as a drawing).

Previous studies of celestial motion have used variations or combinations of the following: surveys, one-on-one interviews, or interviews with models and/or drawings. Each of these methods has advantages and disadvantages. Surveys have been used to assess the frequency of students’ alternative ideas (Trumper, 2001a, 2001b; Sadler, 1998) but are limited by the assumption that the researcher has identified all of the potential alternative ideas ahead of time and presented these in a manner comprehensible to the student. Interviews can overcome this difficulty by allowing the students to express themselves without limitation of choosing one particular idea. However a verbal-only
interview is limited by the verbal capabilities of the student, especially when considering
the scientific vocabulary of children, and perceptiveness of the interviewer in interpreting
the students’ responses about the three-dimensional topics of astronomy. Some
researchers have overcome some of this difficulty by the use of models of objects such as
the earth and moon (Baxter, 1989; Atwood & Atwood, 1995) or the use of drawings

Sharp’s (1996) report of the results of interviews with 42 students, ages of 10 and
11 years, included questions about the apparent motion of the sun, moon and stars. While
he reported that 76% of these students were able to describe verbally and/or with gestures
and drawings the path of the sun, also reported that 62% were unaware of the apparent
motion of the moon. Based on the description of how the students were interviewed
(verbatim interaction with the addition of drawings and gestures), and the spare nature of
the reported outcomes, the study appears to lack the depth of information necessary to
truly assess the students’ ideas about apparent celestial motion.

For the present study I chose to use a one-on-one interview, as have many
previous studies of astronomy education (e.g. Sharp, 1996; Baxter, 1989; Vosniadou &
Brewer, 1994). However, I chose not to use drawings or models to represent the sun,
moon and earth as have been used before. First, models of the celestial objects are useful
when talking about heliocentric topics. When assessing how the students think these
objects actually move in relation to each other, especially as seen from an observer
outside of the earth, the use of physical models is an advantage. However, in this study I
was interested in assessing what the students think these motions would look like from
the surface of the earth not outside of the earth. Using drawings to assess these ideas
would limit the students by forcing them to translate the three-dimensional view from the surface of the earth to a flat two-dimension paper (for example, the sun starts in the eastern sky, rises up into the southern sky, and then sets on the opposite side of the sky – a challenge to fully represent on paper).

For these reasons, I chose to use a different type of model when interviewing the students – a model of the actual sky created by an artificial dome that resembled a very small planetarium. To represent the sun, moon and stars I used a small flashlight that could be shone upon the domed “sky” to simulate the apparent motion. This construction has an advantage over previous methods used to assess celestial motion because students were placed in a setting that was more contextually relevant to their experiences relating to these concepts. Previous studies were not as contextually aligned with students’ knowledge of apparent celestial motion. This setting also gave the students a range of freedom in how they chose to explain their ideas of how the sun, moon and stars seem to move. This allowed me to assess not only the awareness of motion but the range of possible ways that students might imagine the apparent motion of these celestial objects including rising and setting as well as moving without rising or setting.

The artificial dome setting was compared to two other interview settings through pilot testing. The three possible interview scenarios were pilot tested in June 2004 with six third-grade students at Dresden Elementary, a school serving kindergarten through sixth grade in a small Midwestern town within 30 miles of the other interview sites. In the first scenario, two students were asked to demonstrate their answers using small pictures of the sun and moon on a photograph showing a clear sky above an open landscape. The image was in color on an 8 ½” X 11” sheet of paper (see Appendix A).
In the second scenario, two students were taken outside and asked to demonstrate their answers by pointing to the actual sky. In the third scenario, two students were interviewed in a small portable dome and asked to demonstrate their understanding using a flashlight to represent the sun, moon and stars.

In the first scenario (photograph), the two students seemed confused in attempting to use the representation to show their answers. I was also not sure that I understood what they were trying to explain or demonstrate. In the second scenario (outdoors), the students were distracted by the setting (people passing by, objects in the sky such as clouds and the real sun) and I found it challenging to interpret and record the answers they gave by pointing at the expanse of the real sky. The third scenario (small dome) provided a convenient setting for the students to demonstrate their ideas and for me to record their answers. This third option was chosen for the final interview setting.

A second round of pilot testing interviews with third grade students were conducted at Dresden Elementary in October 2004. Twelve students from this class were interviewed to further investigate how the students’ would answer the questions in the revised interview protocol. These results were used to finalize the interview questions used in Studies A and B.

**Interview Setting**

The interview setting described in this section was used in both Studies A and B. The setting chosen for this interview was a small dome (shown in Figures 3.1 and 3.2). This setting allowed the student to pretend they were looking at the real sky. The dome sits on a 4 ft high structure that is open so the student and interviewer are visible from outside of the dome. The full height of the structure is approximately 6 ft. The students
were given a small flashlight which they used to represent the sun, moon, and a star during the interview. The students used the flashlight to indicate the position and movement of these objects in the sky, as prompted during the interview.

Each student was interviewed individually. Interviews with the first and third grade students at Adventure Elementary were conducted in the hallway near their classroom. Interviews with the eighth grade students at Pekin were conducted in an unused classroom. Two methods were used to record the students’ answers. All interviews were recorded using a small digital recorder placed next to the student. In order to capture this visual information, I created a template of the dome for each section of the interview (see Appendix B). For example, Figure 3 illustrates the diagram for a student who demonstrated the path of the sun as a straight line through the zenith at noon. The numbers correspond to specific questions (“1” is first thing in the morning, “2” is at 10AM, “3” is at lunchtime or noon, “4” is in the afternoon, “5” is at the end of the day). The questions at the bottom of the record sheet are there for guidance for the interviewer.
and are not exact statements of the questions used during the interview. A more complete description of the interview questions is found in the section below: Interview Protocol.

Similar diagrams were made for each student’s answers about the path of the sun in winter, the path of the moon and the motion of the stars. Students were also asked to draw pictures of the moon for use in assessing their understanding of the changing appearance of the moon. The combination of these the diagrams and audio recordings allowed me to recreate each student’s answers for later coding.

One source of concern with the interview protocol was the students’ ability to use the dome as a representation of the sky and the flashlight as a representation of the sun (or moon or a star). At the beginning of the interviews, I explained to each student that the dome represented the sky and that the bottom of the dome was where the sky met the ground. While there does not appear to be any relevant research on early elementary students’ understanding of a dome representing the sky (for example, a planetarium model) there are some related studies that may help us understand how children will interact with this representation. DeLoache, Peralta de Mendoza and Anderson (1999) investigated children’s understanding of symbol use. They looked at 5- through 7-year-olds use of a scale model as a source of information about a larger space. Children in this study were able to make the connection between a small scale model of a room and the full scale version without instruction, though younger participants required scaffolding to perform at the same level. This suggests that students, even as young as first grade, are capable of making the kind of connections between representations and the actual objects/places that are needed to understand how the artificial sky relates to the real sky.
What do you like to do outside in the summer time?
1. Can you show me where the sun is first thing in the morning?
2. What about a little later in the morning – where is the sun?
3. Where is the sun at lunchtime?
4. Where is the sun in the afternoon around when school is done?
   Now let’s imagine that it’s the end of the day.
5. What happens to the sun at the end of the day? Show me.
   Does the position of the sun change during the day?
6. Can you show me how it changes?
   Remind that we are pretending that it is summer.
7. Can you show me how high the sun will get in the sky today?
8. Is that directly overhead?

Figure 3.3: Example record sheet used during an interview
However, some of the younger students did need additional help in figuring out how to use the dome representation though they appeared to catch on after a short amount of instruction. A few students pointed at the wall (outside of the dome structure) instead of the dome when asked for the location of the sun during the day. I reminded them that the dome was the sky and the bottom of the dome was where the sky meets the ground to help them refocus on the sky representation. A few students seemed unsure where to point when asked where the sun is first thing in the morning. For these students I asked them if the sun was high or low. Based on their response, I indicated where high and where low would be on the dome to get them started. After that they were not given any additional assistance.

**Interview Protocol**

This study used semi-structured interviews. I conducted the interviews in a conversational tone so that the young children would feel comfortable about expressing their ideas. The questions in the interview protocol were sometimes modified depending on the answers provided by the students in order to either help the students make sense of the questions or to probe for more information. In some cases, questions were not asked if they did not make sense based on earlier responses. For example, I asked the students to draw a picture of the moon and then asked “Does the moon ever look different than that?” Four students responded that the moon never looks different and did not draw any additional shapes, even when prompted with additional questions (such as “Does the shape of the moon ever change? Does it always appear circular in the sky?”). For these students I did not ask “How long does it take for the shape of the moon to change?” or “Does the shape of the moon change during the course of one night?” The questions
were designed to be open to the students’ alternative ideas. I tried to avoid using language that would assume that the students held specific ideas about the appearance and motion of the sun, moon and stars.

The topics of apparent celestial motion were addressed in the following order during the interview:

1. The apparent motion of the sun in summer
2. The apparent motion of the sun in winter
3. Comparison of the sun’s path between summer and winter
4. The actual motion of the sun in the sky today
5. The changing appearance of the moon
6. The apparent motion of the moon
7. The apparent motion of the stars
8. The sun at night and what happens to make it day

Each of these themes addresses an aspect of apparent celestial motion and the changing appearance of celestial objects in the sky. The third theme, the seasonal comparison of the sun’s path across the sky, is only briefly addressed via direct questioning during the interview but is explored more thoroughly by comparing the students’ answers to themes 1 and 2 during analysis. A ninth theme was also analyzed: comparisons of the disappearance of the sun and moon. Like the third theme, the ninth theme was examined based on students’ responses to other sections of the interview rather than directly asking the students to compare.

The themes were further broken down into specific categories that allowed me to classify the student’s understanding of the theme from which it arose. These categories were developed both from ideas that I expected to observe and ideas that emerged as I analyzed the interviews. Table 3.2 lists these themes, categories, and the associated interview questions. Categories that were developed from concepts that emerged during the analysis are indicated in the table with an asterisk (*). Each theme and set of
categories is described in more detail in the analysis section where I will discuss the coding for each category.

The interviews with the first grade students in Study A had an average length of 13.7 minutes (SD=3.6). The average length for the third grade student interviews was 12.6 minutes (SD=2.2). The average length for the eighth grade student interviews was 10.7 minutes (SD=1.8).

### Table 3.2 Categories and the associated interview questions

<table>
<thead>
<tr>
<th>Category</th>
<th>Sample interview questions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Theme 1: The apparent motion of the sun in summer</strong></td>
<td></td>
</tr>
</tbody>
</table>
| Is the path of the sun accurate? (Spath) | Where is the sun first thing in the morning?  
Where is the sun at 10 o’clock?  
Where is the sun at noon or lunchtime?  
Where is the sun in the afternoon when school gets out?  
What happens to the sun at the end of the day?  
Show me again what the sun does throughout the entire day.  |
| Is the sun below the zenith at its highest point? (Szen) | Where is the sun when it is highest in the sky?  
Is that directly overhead?  |
| Is the sun highest at noon? (Snoon) | Where is the sun at noon or lunchtime?  |
| Is the sun’s motion continuous? (Scon)* | This was assessed through student responses to questions in previous categories.  |
| **Theme 2: The apparent motion of the sun in winter** |  |
| Is the path of the sun accurate? (Wpath) | Where is the sun first thing in the morning?  
Where is the sun at 10 o’clock?  
Where is the sun at noon or lunchtime?  
Where is the sun in the afternoon when school gets out?  
What happens to the sun at the end of the day?  
Show me again what the sun does throughout the entire day.  |
| Is the sun below the zenith at its highest point? (Wzen) | Where is the sun when it is highest in the sky?  
Is that directly overhead?  |
<table>
<thead>
<tr>
<th>Question</th>
<th>Previous Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the sun highest at noon? (Wnoon)</td>
<td>Where is the sun at noon or lunchtime?</td>
</tr>
<tr>
<td>Is the sun’s motion continuous? (Wcon)*</td>
<td>This was assessed through student responses to questions in previous categories.</td>
</tr>
<tr>
<td><strong>Theme 3: Comparison of the sun’s path between summer and winter</strong></td>
<td></td>
</tr>
<tr>
<td>Does the student show the same type of path in summer and winter? (Cpath)*</td>
<td>This was assessed through student responses to questions in previous categories.</td>
</tr>
<tr>
<td>Is the direction of the sun’s motion the same in the summer and winter? (Cdir)*</td>
<td>This was assessed through student responses to questions in previous categories.</td>
</tr>
<tr>
<td>Is the length of the sun’s path shorter in winter compared to summer? (Clen)</td>
<td>This was assessed through student responses to questions in previous categories.</td>
</tr>
<tr>
<td>Is the sun’s altitude lower in winter compared to summer? (Calt)</td>
<td>(Summer) Where is the sun when it is highest in the sky? (Winter) Where is the sun when it is highest in the sky? Is that the same as the summer?</td>
</tr>
<tr>
<td><strong>Theme 4: The actual motion of the sun in the sky today</strong></td>
<td></td>
</tr>
<tr>
<td>Is the sun actually moving in the sky outside right now? (Sacc)</td>
<td>If we went outside right now and saw the sun in the actual sky, would it seem to be moving?</td>
</tr>
<tr>
<td><strong>Theme 5: The changing appearance of the moon</strong></td>
<td></td>
</tr>
<tr>
<td>Does the appearance of the moon change on the order of days or up to a month? (Mapp)</td>
<td>Can you draw a picture of the moon for me? Does the moon ever look different than that? How long does it take for the shape of the moon to change?</td>
</tr>
<tr>
<td>Does the shape of the moon appear to change over the course of one night? (MCN)</td>
<td>Does the shape of the moon change during the course of one night?</td>
</tr>
<tr>
<td>Is the moon ever visible during the daytime? (Mday)</td>
<td>Can we ever see the moon during the day?</td>
</tr>
<tr>
<td>Where is the moon when we can’t see it? (MoNV)</td>
<td>Where is the moon when we can’t see it?</td>
</tr>
<tr>
<td>Theme 6: The apparent motion of the moon</td>
<td>Is the path of the moon accurate? (Mpath)</td>
</tr>
<tr>
<td>Does the student show the same path for the moon as for the sun? (Msun)*</td>
<td><em>This was assessed through student responses to questions in previous categories.</em></td>
</tr>
<tr>
<td>Is the moon’s motion continuous? (Mcon)*</td>
<td><em>This was assessed through student responses to questions in previous categories.</em></td>
</tr>
</tbody>
</table>

| Theme 7: The apparent motion of the stars | Do the stars appear to move at night? (MV) | Let’s pretend that it’s just gotten dark outside. Let’s pretend that is a bright star up there. Where would we see that star at midnight? |
| Do we see different stars during the night? (StDif) | If we went outside just before sunrise would we see the same stars as we saw just after sunset? |
| Where are the stars during the daytime? (StDay) | We don’t see any stars in the sky during the daytime. Why don’t we see them? |

| Theme 8: The sun at night and what happens to make it day | Where is the sun at night? (SunN) | Where is the sun when we can’t see it at night? |
| What happens to make it daytime? (SunD) | What is going to happen to make it daytime again? |

| Theme 9: Comparison of the disappearance of the sun and moon | Does the student use the same explanation for why we can’t see the sun at night and why we cannot always see the moon? (SuMo) | *This was assessed through student responses to questions in previous categories.* |
Changes in the interview protocol for Study B

The students’ understanding of apparent celestial motion was assessed both before and after the planetarium program using the same interview protocol as was used in Study A, with one minor change. Theme 4, listed above, was omitted. This resulted in dropping the following question: If we saw the actual sun in the sky would it actually be moving? This question did not strongly relate to the material chosen for the planetarium program and the results from the interviews with the first and third grade students suggest that this is a topic that may need more in-depth coverage than a 45-minute planetarium program could provide.

The mean length of time between the initial interview and the planetarium program was 9.0 days before (SD = 3.5). The mean length of time between the planetarium program and the final interview was 6.9 days (SD = 1.9). The mean length of the interviews was 12.0 minutes (SD = 3.1) before the program and 10.5 minutes (SD = 2.4) after. Some of the decrease in time can be attributed to three factors. First, I did not ask the students to tell me what they like to do outside in the summer and winter during the post-instruction interview. Second, I did not have to explain how the dome represents the sky or the flashlight represents the sun. Third, the students were more comfortable and familiar with the concepts and spent less time considering their responses.

Description of the Planetarium Program

In this section I will describe the planetarium program which I used in Study B. The planetarium program was laid out in roughly nine segments, which includes some repetition of topics. The order that the information was presented was based on the ease
of transition from showing the sun during the day, then the stars at night, followed by the introduction of the moon during the daytime sky. The simplified script version of the planetarium program can be found in Appendix C. I taught each of the planetarium programs that were part of this study. The teachers were present in the planetarium during the programs.

Introduction

Once all of the children were seated, I began by explaining the function of the planetarium instrument and room so that they would know how the planetarium can be used to represent the sky. I explained that the dome is going to be the sky and then asked the students to suggest things that we might see in the sky. This would often include the sun, stars, moon, planets, clouds, birds, airplanes, etc. I explained to the students that the instrument in the middle of the room would shine lights on the ceiling to show us the objects we can see in the sky during the day and the night. I also explained to the students that the planetarium could show us things happening very quickly that really happen very slowly. This point was emphasized throughout the planetarium program. Finally, I explained that the planetarium instrument will rotate to show the motion of the objects in the sky but that in the real sky the motion is caused by the rotating earth. This was also demonstrated with the help of an earth globe.

The Apparent Motion of the Sun in Summer, Part I

This section of the program was designed to introduce the students to the apparent motion of the sun. We started the planetarium program by pretending that it
was the first day of summer, June 21. I asked the students a series of questions to get them thinking about the morning sky:

- What makes it daytime?
- Why is it light outside during the day?
- Where would you look for the sun, first thing in the morning?
- Would it be low or high in the sky?
- Does anyone know what direction the sun is when it rises in the morning?

The questions listed above are representative of the questions asked but not all were used during each program. The planetarium sun had been previously set to the correct position in the sky for June 21, just after sun rise. After the students were given a chance to answer the questions, I turned on the sun (a projector on the central planetarium instrument that shines yellow disc-shaped light onto the dome) and adjusted the dome lights to make the sky look blue. I pointed out the sun in the sky for the students because it is not bright enough to be noticed by students facing away from its position.

The students were asked “Does the sun seem to move in the sky during the day?” They were then asked to first point at the sun and then use to their arms to demonstrate what they think the sun does throughout the entire day. This was the first use of kinesthetic learning techniques during the program. This action was included in order to prompt the students to think about their prior knowledge of the apparent motion of the sun. I then told them that I was going to show them what the sun does during the day using the planetarium to make it seem like the earth is turning. I instructed the students to point at the sun again and follow its motion, reminding them that we are watching time go by very quickly and that the motion we are seeing is caused by the earth slowly rotating. As the students traced the motion I pointed out the directions as the sun rose in the east, passed through the south, and began to set in the western sky.
I stopped the motion of the planetarium instrument as the sun reached the western horizon. I asked the students: What time is now? Can you show me what happens to the sun next? The students then demonstrated that the sun sets below the horizon by pointing down. This was followed by demonstrating the setting of the sun as I reminded them that the sun sets when our part of the earth turns away from the sun.

The Apparent Motion of the Stars, Part I

After the sun set, I turned the lights down and the stars on as the motion continued. This section was designed to introduce the students to the idea that the stars appear to move at night. I asked them to point at the direction where new stars were appearing and then point to where other stars were disappearing below the horizon. I also asked them to pick a star and follow its motion with their arm. This section went by rather quickly and soon it was nearly time for the sun to rise. So I asked the students to point to where they thought they would see the sun again in the sky. As the sun rose, I turned the lights back up and stopped the rotation of the planetarium instrument.

At this point in the program the light in the “star ball” part of the planetarium instrument was still on. The star ball projects the stars onto the dome. This lamp was not turned on when we first observed the daytime sky. The blue lights that make the sky look blue are not bright enough to drown out the light of the stars created by the star ball on the planetarium sky. The result was that the students could still see the stars in the sky during the day and night from this point on (the star projector remained on for the rest of the program). I pointed out this difference from the real daytime sky and talked about why we cannot see the stars during the day even though there are still stars up in the sky.
The Apparent Motion of the Sun in Summer, Part II

I asked the students to show me again what the sun was going to do during the day, to reinforce the motion they had previously observed. Once again I had the students follow the motion of the sun as it rose. But I stopped the sun’s apparent motion once it reached the apex of its path above due south. I asked the students if they knew what time of day it is when the sun is highest in the sky. I then asked the students if the sun, as we see it in the planetarium, is directly overhead. The point that would be directly overhead, the zenith, is directly above the planetarium instrument at the top of the dome. I asked the students to point at that point and then back at the sun to make the connection that the sun did not reach the point directly overhead at its highest point along its path. After this I asked the students to point to where the sun would be in the afternoon and where it would set. These concepts were reinforced by then continuing the apparent motion of the sun until it once again set below the western horizon.

The Apparent Motion of the Stars, Part II

Once the sun had set below the horizon I turned the lights down and stopped the rotating motion. Using a flashlight-like “pointer” that projects an arrow on the dome, I pointed out the stars of the Big Dipper. The students followed along by with their arms and hands as I pointed to each star. I then taught them to trace the line between the two stars at the front of the Big Dipper’s cup to find the North Star, Polaris. We then used this to find the directions North, South, East and West (though the students had already seen the directions with the motion of the sun). These activities were not directly related to the learning goals of the program I designed about celestial motion, but were designed to help them orient on specific stars and get used to finding patterns in the stars.
There were two important learning goals for the apparent motion of the stars in this program: stars appear to move slowly across the sky during the night in a smooth pattern and we see different stars throughout the night because some stars rise and set. To help the students learn these concepts I told the students we were going to play a game, but first I would need to teach them some bright stars and constellations. I chose three bright stars and a noticeable constellation to teach the students. These were Vega and its constellation Lyra (The Harp), Arcturus and its constellation Bootes (The Herdsman), Antares and its constellation Scorpius (The Scorpion) and the constellation Delphinus (The Dolphin). I then told the students that we were going to see which star stayed up the longest during the night and which set first. I instructed them to each choose one star or Delphinus (a very small constellation), point at it, and then follow it as I resumed to motion caused by the rotation of the earth. I pointed to each a few times to make sure the students had time to pick one and point to it.

I slowly ran the motion of the projector allowing the night to progress as the students followed their chosen star or constellation. At the end of the night, when the sun had risen I turned the lights on. I asked the students to tell me which had set first and which remained in the sky. Antares and Arcturus had set below the western horizon but Vega and Delphinus remained in the sky as night turned to day. At this point, I reminded the students that we had seen the sun rise and set and then rise and set again. I asked them, “How many days has it been so far?” (Two days.)

The Orbit of the Moon

Up to this point in the program, the students have only explored the apparent motion of the sun and stars. To begin the section discussing the moon, I first began with
a heliocentric perspective. I brought out a ball to represent the moon and for a volunteer to hold the earth-globe. I showed the moon ball slowly orbiting around the earth-globe and told the students that this takes 28 days for the moon to go all the way around the earth. I asked the student holding the earth-globe to spin the globe around and told the students that half of the time our side of the earth is facing towards the moon and half of the time it is facing away from the moon. Then I asked the students to all stand up and pretend to be the earth. I held up the moon ball and asked them to slowly spin around like the earth. I pointed out that sometimes they are facing towards the moon and sometimes they are facing away from the moon.

**The Apparent Motion of the Moon**

I asked the students “Where will we see the moon when it first rises?” The students then pointed out their predictions. I turned on the moon projector, though the students could not yet see it because it was still below the horizon. The moon projector was set to show a waxing crescent phase which means it will rise very soon after the sun. I tell the students that we will watch for the moon to appear as the day goes on and the sun rises. Soon the moon appeared over the horizon and I stopped the motion. Once the moon has appeared and the students have seen where it rose, I asked the students “Is it day or is it night?” This was done to bring up the idea that the moon can be seen in the day and the night. The students were able to see both the sun and moon in the sky. I also pointed out that the side of the moon that is visible, the “crescent shape,” is the side facing towards the sun. When the students are older and learn about how the moon’s light is reflected sunlight, this information will be more useful. Then, just as with the sun, I asked the students to show me with their arms and hands what they think the moon
will do throughout the day. Finally, I asked them to point at both the sun and the moon and “see if you can follow both objects as they move across the sky.” This was to help reinforce the idea that the sun and moon follow the same type of path across the sky and in the same direction.

Once the sun has set, I turned the lights off and stopped the motion so that the crescent moon was just above the western horizon. I asked the students if the shape of the moon seemed to change during the day in order to reinforce the idea that the appearance of the moon does not change noticeably during one day.

Next, I projected some slides showing different phases of the moon. The student interviews revealed that most children, even at this age, have a basic knowledge of the variety of phases of the moon so little time was spent on this topic. I showed the pictures of the waxing crescent, first quarter moon (also known as the waxing half moon) and the full moon.

The next topic covered in the planetarium was the changing appearance of the moon coupled with the changing rise and set time for the moon. In reality, these changes are coupled by the moon’s orbit around the earth which alters its alignment with the sun and earth. However, a full treatment of this topic is beyond the scope of a planetarium program for early elementary students. My focus during this program was to show the students how long it takes for the phases to change. So I told the students that we were going to jump ahead and look at the sky three days from now. This is approximately how long it would take for the phase of the moon to change from the waxing crescent they had just seen to the first quarter moon. I set the projector to show a first quarter moon and ran the motion of the projector to move us to sunrise. The students were not able to see the
phase of the moon change because it was below the horizon while I made the change to the moon projector.

As the sun rose, I asked the students “Where do you think we will see the moon rise now? Let’s watch and see.” The students observe the moon rise, but much later than the crescent (it is about noon with the sun at due south when the first quarter moon rises). I asked the students if they thought the moon looked the same or different than before and to note that it is farther from the sun in the sky. We then continued to watch the apparent motion of the sun and moon across the sky as the planetarium simulates the rotation of the earth. The sun sets well before the moon does so the students can see the moon and stars appear to move in the same direction towards the western horizon during the night. As the moon was about to set, I asked the students again “Did the shape of the moon seem to change as we watched it appear to move across the sky?” They should respond that it did not.

The entire process used for the first quarter moon was repeated to show the apparent motion of the full moon (this time I told the students we would be jumping ahead in time by one week). The moon is now far from the sun in the sky and as the full moon rises, the sun sets. I explained to the students that, as the moon orbits the earth, it appears to get farther from the sun in the sky and we can see more of it illuminated. This is a concept that I am not expecting the students to fully retain or understand as they are likely to need more experience with three-dimensional models of the earth-sun-moon system to master this concept.

The moon projector was then turned off.
The Apparent Motion of the Sun in Winter

In order to demonstrate the difference between the sun’s path in summer and winter I chose to move the sun to its position on the first day of winter, December 21. This was done by first turning on the ecliptic projector, a line that shows where the sun is with respect to the background of stars on any day of the year. I told the students that the ecliptic was like a calendar. I then moved the sun’s projector to the correct position for the first day of winter, and rotated the entire sky until the sun was just over the eastern horizon. On the first day of winter the sun rises its furthest south of east. On the first day of summer the sun rises its furthest north of east. So I asked the students to point to where the sun was when they saw it rise on the first day of summer in order to emphasize the difference between the two rising positions.

I asked the students to again use their hands and arms to show me what they think the sun will do in the sky in the winter. This was followed by the same procedure as in summer: the students pointed to the sun and followed its apparent motion as the planetarium projector simulated the rotation of the earth. As the sun reaches its highest point in the south I stopped the motion and asked the students to point to where they remember the sun being in the summer at noon (which I confirm with my pointer) to compare the difference in altitude of the sun between summer and winter. I also asked the students, again, if the sun was ever directly overhead. We then continue to follow the motion of the sun until it sets in the south-western sky.
The Stars and Planets Tonight

The format of the end of the show was less structured. I ended by pointing out stars and planets that they could see in the sky tonight as well answering the students questions.

Data analysis

This section will describe how the interview data was analyzed to answer the three research questions listed above for Study A followed by the analysis performed for the research questions of Study B. Both of these studies used the coding scheme described in the section below.

Coding

In the sections below I will describe how each of the categories was coded. The codes represent the students’ ideas, demonstrated and/or verbally indicated, about an aspect of apparent celestial motion. The interviews were not completely transcribed for this analysis. Each interview was coded based on listening to the recording of the interview concurrent with viewing the written diagrams I made during each interview. For each of the categories, I developed a series of codes that described at least one student’s idea about that topic. The codes were developed directly from the substance of the interviews, not a priori.

The codes were grouped by level of accuracy. Each code was designated as accurate, partially accurate, or non-normative. The term “non-normative” refers to concepts that do not closely match the norm of the science community. These accuracy
levels were used in Study B to analyze the change in students’ responses from before to after the planetarium program and will be discussed in more detail later in this chapter.

Two raters individually coded 15% of the students’ responses from Study A (three students from first, third and eighth grade). Inter-rater agreement was calculated by computing the ratio of agreements to the total number of categories (27). There was an 86% agreement when comparing code by code. If only the accuracy levels (accurate, partially accurate, and non-normative) were compared, there was 92% agreement between the raters.

**Theme 1: The apparent motion of the sun in summer**

This theme includes four categories: Spath, Szen, Snoon, and Scon. Each relates to an aspect of the apparent motion of the sun in summer. The Spath category includes codes describe the level accuracy of the shape of the sun’s path across the sky. The Szen category includes codes that describe the location of the sun at its highest point. The Snoon category includes codes describing the time at which the sun reaches its highest point. And the Scon category includes codes that describe the continuous nature of the sun’s motion across the sky. Each of these categories and the corresponding codes are described in Table 3.3.

<table>
<thead>
<tr>
<th>Category</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spath</strong>: Is the shape of the sun’s path accurate?</td>
<td><strong>Accurate</strong></td>
</tr>
<tr>
<td></td>
<td>Spath-1: The sun’s path is a smooth curve that does not pass through the zenith. The sun rises and sets on opposite sides of the sky. This means that there must be more than 45 degrees between where the sun rises and where it sets, as measured in azimuth (along the horizon).</td>
</tr>
</tbody>
</table>
**Partially Accurate**

Spath-2: The student demonstrates the same path as described in the accurate code EXCEPT the sun passes through the zenith.

Spath-2\textsuperscript{b}: The student demonstrates two different paths during the interview. One of these is Spath-1 or Spath-2.

**Non-normative**

Spath-3: The path of the sun includes rising and setting and does not pass through the zenith but also includes other inaccuracies such as remaining at the same altitude.

Spath-4: The path of the sun includes rising and setting but also has a sharp turn of more than 45 degrees within the path. In other words, the path is not a smooth curve.

Spath-5: The student demonstrates that the rising position of the sun is less than 45 degrees (in azimuth) from the setting position, thus the sun remains in the same octant of the sky throughout the day. Typically this meant that the student believes that the sun rises and sets in the same position on the horizon.

Spath-6: The motion that the student demonstrates does not resemble the actual path of the sun. For example, the student may show the sun circling around the zenith rather than rising or setting. Or the path may cross the sky in multiple directions throughout the day.

Spath-7\textsuperscript{a}: The student shows more than one non-normative path of the sun during the interview.

<table>
<thead>
<tr>
<th><strong>Szen</strong></th>
<th><strong>Accurate</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the sun below the zenith at its highest point?</td>
<td>Szen-1: When the student demonstrates the path of the sun it does not pass through the zenith. The student also points below the zenith when asked where the sun is when it is highest in the sky AND when asked if that point is directly overhead the student responses with a negative.</td>
</tr>
</tbody>
</table>

**Partially Accurate**

Szen-2: The student gives an inconsistent answer:

1) When asked where the sun is when it is highest, the student points below the zenith and says this is not directly overhead. But earlier the student showed the path of the sun passing through the zenith.

2) When asked where the sun is when it is highest, the student points to the zenith but says that this is not directly overhead.

3) When asked where the sun is when it is highest, the student points to a point below the zenith but says this is directly overhead.

**Non-normative**

Szen-3: The sun passes through the zenith when it is highest in the sky and the student says this is directly overhead.
**Snoon: Is the sun highest at noon?**

**Accurate**
- Snoon-1: The student shows the sun at its highest point at noon.

**Partially accurate**
- Snoon-2: The student indicates that the sun is highest at noon, but also in some way indicates that the sun is highest at some other time of day. This could occur when a student demonstrates a path for the sun where it reaches a higher point before or after the noon position, but later points to the noon position when asked where the sun is highest in the sky.

**Non-normative**
- Snoon-3: The student indicates that the sun is highest at some other time of day.
- Snoon-4: The sun remains at the same altitude (not getting higher or lower) throughout part of the day, including noon. For example, the student may show the sun moving across the sky but staying at the same altitude from 10 o’clock to noon through the afternoon before setting.
- Snoon-5: Student doesn’t know when the sun is highest.

**Scon: Is the sun’s motion continuous?**

**Accurate**
- Scon-1: The student demonstrates that the sun moves continuously throughout the day and does not stop in any one position for an extended period of time.

**Non-normative**
- Scon-1: The student shows the sun remaining in the same position for an extended period of time or changing speeds. For example, some student showed the sun rising up to the zenith in the morning and remaining there until the end of the day when the sun then set below the horizon.

*Spath-2b and Spath-7 both code for students who demonstrated two different paths for the sun. In Study A, these students are listed together. In Study B, these are considered as separate codes.*

A student was assigned to a specific code in each category based on a combination of how the student demonstrated the motion using the flashlight in the dome and the verbal responses they made as they demonstrated the motion or answered questions about what they demonstrated.
Theme 2: The apparent motion of the sun in winter

The same four categories were used to classify the students’ understanding of the apparent motion of the sun in winter (Wpath, Wzen, Wnoon, and Wcon). These were coded using the same criteria as described in the section above for the summer with one additional code. The code Wzen-4 was added to describe students who did not show enough of the sun’s path to determine the sun’s location throughout the day.

Theme 3: Comparison of the sun’s path between summer and winter

This theme includes four categories: Cpath, Cdir, Clen, and Calt. Each category compares an aspect of the apparent motion of the sun in summer to its motion in winter. The Cpath category includes codes that describe whether or not the students gave the same description for the path of the sun in summer and winter. The Cdir category includes codes that describe the direction of the sun’s motion for whether or not the student shows the sun’s motion across the sky is in the same direction in summer and winter. The Clen category includes codes that describe the accuracy of the length of the sun’s path in summer compared to winter. The accurate description shows the path of the sun as significantly shorter in winter compared to summer. Finally, the Calt category includes codes describing the accuracy of how the students compare the sun’s altitude in summer and winter. The sun appears lower in the sky in winter.

The students were not asked to specifically compare each of these topics directly (path, direction, or length) except for the comparison of the sun’s highest altitude. This was coded by both comparing where the student pointed as the highest point in summer and winter and by asking them, in winter, if where they pointed for the sun’s highest point was the same as during summer. For the other three categories, the responses were
coded by examining their responses to the questions in the summer and winter portions of the interview.

### Table 3.4 Codes developed for the comparison of the sun’s path in summer and winter

<table>
<thead>
<tr>
<th>Category</th>
<th>Codes</th>
</tr>
</thead>
</table>
| **Cpath**: Does the student show the same type of path in summer and winter? | **Accurate**<br>Cpath-1: The student describes the same type of path for the sun in both summer and winter.  
**Partially accurate**<br>Cpath-2: The student describes similar paths for the sun in summer and winters except the directions are shifted by more than 45 degrees.  
**Non-normative**<br>Cpath-3: The student gives a different description for the sun’s motion in summer and winter. |
| **Cdir**: Is the direction of the sun’s motion the same in summer and winter? | **Accurate**<br>Cdir-1: The sun’s motion is in the same direction across the sky in summer and winter.  
**Non-normative**<br>Cdir-2: The sun’s motion across the sky is in the opposite direction in summer compared to winter.  
Cdir-3: The sun’s motion across the sky is shifted by more than 45 degrees (but is not exactly opposite) in summer compared to winter.  
Cdir-4: The paths that the students describe for summer and winter are not directionally comparable. This occurred for non-normative paths where the student did not show the sun rising and setting on opposite sides of the sky. |
| **Clen**: Is the length of the sun’s path shorter in the winter compared to the summer? | **Accurate**<br>Clen-1: The student accurately shows that the path of the sun in winter is shorter than the path of the sun in summer. This was determined by comparing the distance between the rise and set positions, measured in degrees of azimuth, in summer to winter. The difference needed to be greater than 45 degrees to counted as intentional. |
**Non-normative**

Clen-2: There is no significant difference in the length of the sun’s path across the sky. This includes paths where the sun rises in the same location in summer and winter as well as sets in the same location on the opposite side of the sky in summer and winter. It also includes paths that are the same length but the rise and set positions are shifted when comparing the seasons.

Clen-3: The path of the sun is significantly longer in winter than in summer. The difference needed to be greater than 45 degrees to be counted as significant and not unintentional.

Clen-4: The path of the sun in summer is not comparable in length to the path in winter. This occurred for non-normative paths where the sun did not cross the sky, such as rising and setting in the same place, or circling around the sky.

**Calt:** Is the sun’s altitude lower in winter compared to summer?

**Accurate**

Calt-1: The sun’s altitude is lower in winter compared to summer. For the difference in altitude to be counted the student need to both demonstrate the difference by pointing lower in winter and to answer the question “Is that different than it was in summer?” by saying “yes” or “yes it is lower.”

**Partially accurate**

Calt-2: The student says that the sun’s altitude is lower in the winter but does not demonstrate this accurately. This could have meant that the student pointed to the same position for the sun’s highest altitude in summer and winter. Or the student may have said that the sun is lower in winter and pointed to a lower position when asked where the sun is highest, but the paths demonstrated went through the same highest altitude (usually the zenith).

**Non-normative**

Calt-3: The highest altitude is the same in summer and winter. The student indicates this idea both by pointing with the flashlight and by verbally confirming that they are in the same position.

Calt-4: The sun reaches the same altitude in summer and winter, but at different times of day.

Calt-5: Student indicates that the sun is higher in the winter than the summer.

Calt-6: The student did not give enough information in order to make a comparison.
Theme 4: The actual motion of the sun in the sky today

This theme includes only one category, Sacc, which corresponds to the question “Is the sun actually moving in the sky outside right now?” This was asked to determine how the students would describe the motion of the sun at a particular moment in time, not over the course of an entire day. The students were both asked if the sun seems to be moving in the sky right now and to explain the answer that they gave. This category was only coded based on a verbal response. The codes in this category were not assigned values of accurate, partially accurate and non-normative because this theme was not included in the interviews conducted for Study B.

Table 3.5 Codes developed for the actual motion of the sun in the sky today

<table>
<thead>
<tr>
<th>Category</th>
<th>Codes</th>
</tr>
</thead>
</table>
| **Sacc:** Is the sun actually moving in the sky outside right now? | Sacc-1: The sun does not appear to be moving because it is moving very slowly.  
Sacc-2: The sun does not appear to be moving because we (the earth) are moving.  
Sacc-3: The sun does not appear to be moving because it is so far away.  
Sacc-4: The sun does appear to be moving because we are moving.  
Sacc-5: The student is not able to explain why the sun does not appear to be moving.  
Sacc-6: The student gives a unique explanation. Examples include: the sun only moves when it is time for it to go down at night or it only appears to be moving in the summer when it is warm and not during the winter when it is cold. |

Theme 5: The changing appearance of the moon

Four categories were included under the topic of the appearance of the moon: Mapp, MCN, Mday, and MoNV. The first two categories deal with the length of time it takes for the appearance of the moon to change. The students were coded for the Mapp
and MCN categories based on questions asked after the students drew pictures of what the moon looks like in the sky. The category Mday includes codes that describe the accuracy of students’ knowledge of the moon’s appearance in the daytime sky. The students were also asked to explain where the moon is when it is not visible in the sky. All of these categories were coded based on the students’ verbal responses to questions, though some students demonstrated the moon’s motion when asked about where the moon is when not visible.

Table 3.6 Codes developed for the changing appearance of the moon

<table>
<thead>
<tr>
<th>Category</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mapp: Does the appearance of the moon change on the order of days or up to a month?</td>
<td>Accurate</td>
</tr>
<tr>
<td>Mapp-1: The student says that it takes more than a day but less than a month for the shape of the moon to appear to change significantly.</td>
<td></td>
</tr>
<tr>
<td>Non-normative</td>
<td></td>
</tr>
<tr>
<td>Mapp-2: It takes less than a day for the shape of the moon to change.</td>
<td></td>
</tr>
<tr>
<td>Mapp-3: It takes over a month for the shape of the moon to change.</td>
<td></td>
</tr>
<tr>
<td>Mapp-4: The shape of the moon never changes.</td>
<td></td>
</tr>
<tr>
<td>Mapp-5: The student does not know.</td>
<td></td>
</tr>
<tr>
<td>MCN: Does the shape of the moon appear to change over the course of one night?</td>
<td>Accurate</td>
</tr>
<tr>
<td>MCN-1: No, the shape does not change during the course of night or the change is too small to notice.</td>
<td></td>
</tr>
<tr>
<td>Non-normative</td>
<td></td>
</tr>
<tr>
<td>MCN-2: Yes, the shape of the moon changes noticeably during the course of one night.</td>
<td></td>
</tr>
<tr>
<td>MCN-3: The shape of the moon never changes.</td>
<td></td>
</tr>
<tr>
<td>MCN-4: The student does not know.</td>
<td></td>
</tr>
<tr>
<td>Mday: Is the moon ever visible during the daytime?</td>
<td>Accurate</td>
</tr>
<tr>
<td>Mday-1: Yes, the moon can sometimes be seen during the daytime.</td>
<td></td>
</tr>
</tbody>
</table>
Theme 6: The apparent motion of the moon

This theme includes three categories: Mpath, Msun, and Mcon. The Mpath category includes codes describing the accuracy of how the student demonstrated the apparent motion of the moon. The Msun category includes code describing whether or not the student described the same path for the sun and the moon. This was done based on how they demonstrated both the sun and the moon’s paths in the separate sections of the interview, not from directly asking them to compare these paths. This category was not used in Study B. The Mcon category includes codes for whether or not the student described the motion of the moon across the sky as continuous. As with the sun, I found
that some students believe that the moon stays in one place for an extended period of time. Mcon was also not used in Study B.

Table 3.7 Codes developed for the apparent motion of the moon

<table>
<thead>
<tr>
<th>Category</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mpath</strong>: Is the path of the moon accurate?</td>
<td><strong>Accurate</strong>&lt;br&gt;Mpath-1: The moon’s path is a smooth curve that rises and sets on opposite sides of the sky. The moon does not pass through the zenith.  &lt;br&gt;<strong>Partially accurate</strong>&lt;br&gt;Mpath-2: The moon’s path is a smooth curve that rises and sets on opposite sides of the sky and also passes through the zenith or may begin below the zenith straight down.  &lt;br&gt;Mpath-3: The student demonstrates two different paths for the moon. One of the paths is accurate or partially accurate.  &lt;br&gt;<strong>Non-normative</strong>&lt;br&gt;Mpath-4: The student demonstrates a path that does not fit in any other code but the path includes rising and/or setting (this may include a sharp turn in the path).  &lt;br&gt;Mpath-5: The student demonstrates that the rising position of the moon is less than 45 degrees (in azimuth) from the setting position, thus the moon remains in the same octant of the sky throughout the day. Typically this meant that the student believes that the moon rises and sets in the same position on the horizon.  &lt;br&gt;Mpath-6: The moon moves around the sky but does not rise or set. Most students who were assigned this code demonstrated the moon circling around the sky.  &lt;br&gt;Mpath-7: The moon remains in one place in the sky and never moves.  &lt;br&gt;Mpath-8: The moon rises and sets but spends most of its time up at the zenith.  &lt;br&gt;Mpath-9: The student is unable to demonstrate the motion of the moon.</td>
</tr>
</tbody>
</table>
| **Msun**: Does the student show the same path for the moon as for the sun? | **Accurate**<br>Msun-1: The paths shown for the sun and the moon are very similar. Direction is the same.  <br>**Partially Accurate**<br>Msun-2: The paths shown for the sun and the moon are very similar but the directions are skewed by more than 45 degrees.  <br>Msun-3: The paths of the sun and the moon have some similar
features. For example, the moon’s path is a smooth curve through the zenith and the sun’s path is a smooth curve that does not pass through the zenith.

Msun-4: The student shows more than one path for the moon but one of these is similar to the path of the sun.

**Non-normative**
Msun-5: The path of the sun is not similar to the path of the moon.

<table>
<thead>
<tr>
<th><strong>Mcon:</strong> Is the moon’s motion continuous?</th>
<th><strong>Accurate</strong></th>
<th><strong>Non-normative</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mcon-1: The moon moves continuously. It does not remain in one place for extended periods of time.</td>
<td>Mcon-2: The moon stays in one place for extended periods of time. For example, the moon remains at the zenith through out most of the night. Mcon-3: The moon stays in one place and never moves. Mcon-4: The students’ answer is unclear or inconsistent.</td>
</tr>
</tbody>
</table>

**Theme 7: The apparent motion of the stars**

There were three categories used to assess the students’ understanding of the apparent motion of the stars: MV, StDif, and StDay. The MV category includes codes describing the students’ understanding of the stars’ motion at night. A student needed to both demonstrate with the flashlight and say that the stars appear to move to be coded as accurate, but they did not need to indicate that the stars rise and set. This was not coded to see if a student showed the accurate path of a star rising and setting. The category StDif includes codes describing the concept that we see different stars through out the night. This was assessed through the students’ verbal responses to questions about the stars. The final category in this theme, StDay, includes codes describing the students’ responses to questions about what happens to the stars when the sun comes up.
Table 3.8 Codes developed for the apparent motion of the stars

<table>
<thead>
<tr>
<th>Category</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV: Do the stars</td>
<td><strong>Accurate</strong></td>
</tr>
<tr>
<td>appear to move at night?</td>
<td>MV-1: The student indicates that the stars appear to move during the</td>
</tr>
<tr>
<td></td>
<td>night and is able to demonstrate a star appearing to move. The</td>
</tr>
<tr>
<td></td>
<td>student does not need to represent an accurate path for the stars</td>
</tr>
<tr>
<td></td>
<td>but the motion should be similar to a star moving across the sky.</td>
</tr>
<tr>
<td></td>
<td>The demonstration does not need to include rising and setting but</td>
</tr>
<tr>
<td></td>
<td>the path can be mostly straight up and straight back down. The</td>
</tr>
<tr>
<td></td>
<td>motion should cover a significant portion of the sky and not move</td>
</tr>
<tr>
<td></td>
<td>in all directions, or back and forth.</td>
</tr>
<tr>
<td></td>
<td><strong>Partially Accurate</strong></td>
</tr>
<tr>
<td></td>
<td>MV-2: The student says that the stars appear to move but there are</td>
</tr>
<tr>
<td></td>
<td>inaccuracies in the motion (such as the stars moving in all</td>
</tr>
<tr>
<td></td>
<td>directions or moving back and forth across the sky), or the</td>
</tr>
<tr>
<td></td>
<td>student does not demonstrate the motion s/he describes or the</td>
</tr>
<tr>
<td></td>
<td>student indicates that the motion takes longer than just one</td>
</tr>
<tr>
<td></td>
<td>one night one night.</td>
</tr>
<tr>
<td></td>
<td>MV-3: The student gives conflicting answers. First the student may</td>
</tr>
<tr>
<td></td>
<td>say that the stars do not appear to move but later does indicate</td>
</tr>
<tr>
<td></td>
<td>they appear to move.</td>
</tr>
<tr>
<td></td>
<td><strong>Non-normative</strong></td>
</tr>
<tr>
<td></td>
<td>MV-4: The stars do not appear to move in the sky. The students</td>
</tr>
<tr>
<td></td>
<td>may have also said that only special stars or shooting stars move.</td>
</tr>
<tr>
<td></td>
<td>MV-5: Stars only move at the end of night. The student may say</td>
</tr>
<tr>
<td></td>
<td>that the stars all go to the other side of the earth or go to</td>
</tr>
<tr>
<td></td>
<td>where the moon is when the sun comes up.</td>
</tr>
<tr>
<td>StDif: Do we see</td>
<td><strong>Accurate</strong></td>
</tr>
<tr>
<td>different stars</td>
<td>StDif-1: We see different stars through out the night. The student</td>
</tr>
<tr>
<td>during the night?</td>
<td>explains this using either the rising and setting of stars or the</td>
</tr>
<tr>
<td></td>
<td>rotation of the earth.</td>
</tr>
<tr>
<td></td>
<td><strong>Partially Accurate</strong></td>
</tr>
<tr>
<td></td>
<td>StDif-2: We see different stars through out the night but the</td>
</tr>
<tr>
<td></td>
<td>student does not provide an accurate explanation.</td>
</tr>
<tr>
<td></td>
<td>StDif-3: We see the same stars every night but we see different</td>
</tr>
<tr>
<td></td>
<td>stars across the different seasons or in different places on the</td>
</tr>
<tr>
<td></td>
<td>earth.</td>
</tr>
<tr>
<td></td>
<td><strong>Non-normative</strong></td>
</tr>
<tr>
<td></td>
<td>StDif-4: The student says that we see different stars throughout</td>
</tr>
<tr>
<td></td>
<td>the night but gives a non-normative explanation. The student does</td>
</tr>
<tr>
<td></td>
<td>not think that the stars rise and set.</td>
</tr>
<tr>
<td></td>
<td>StDif-5: We see the same stars all night long, every night.</td>
</tr>
<tr>
<td></td>
<td>StDif-6: The student is unsure or confused</td>
</tr>
</tbody>
</table>
Theme 8: The sun at night and what happens to make it day

Two categories were used to describe the students’ understanding of concepts of day and night: SunN and SunD. The category SunN includes codes for the students’ beliefs about the location of the sun at night. The category SunD includes codes for the students’ answer to the question “What happens to make it daytime?” Coding was based primarily on their verbal responses though some students chose a visual demonstration as well, such as pointing down or showing the sun rising up into the dome/sky.

Table 3.9 Codes developed for the concepts of day and night

<table>
<thead>
<tr>
<th>Category</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SunN: Where is the sun at night?</td>
<td>Accurate</td>
</tr>
<tr>
<td></td>
<td>SunN-1: The sun is on the other side of the earth.</td>
</tr>
<tr>
<td></td>
<td>Partially Accurate</td>
</tr>
<tr>
<td></td>
<td>SunN-2: The sun is down, below the horizon, or is somewhere else on the earth such as another state or country (but does not say the other side of the earth).</td>
</tr>
<tr>
<td></td>
<td>Non-normative</td>
</tr>
<tr>
<td></td>
<td>SunN-3: The sun is behind the moon.</td>
</tr>
<tr>
<td></td>
<td>SunN-4: The sun is behind the clouds.</td>
</tr>
<tr>
<td></td>
<td>SunN-5: The sun goes out into space.</td>
</tr>
</tbody>
</table>
SunN-6: The sun goes somewhere else (underground, in the water, etc.)
SunN-7: The sun is a star in the sky at night.
SunN-8: The sun is still up in the sky but it gives its light to another part of the world or to the moon.
SunN-9: The student does not know or the answer is unclear.

<table>
<thead>
<tr>
<th>SunD: What happens to make it daytime?</th>
<th>Accurate</th>
</tr>
</thead>
<tbody>
<tr>
<td>SunD-1: The earth turns around to face the sun.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Partially Accurate</th>
</tr>
</thead>
<tbody>
<tr>
<td>SunD-2: The sun rises.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Non-normative</th>
</tr>
</thead>
<tbody>
<tr>
<td>SunD-3: The sun is in the sky but the student does not explain how it got there.</td>
<td></td>
</tr>
<tr>
<td>SunD-4: The student indicates that the earth will move around the sun (not rotate or turn) to bring the sun back into our sky.</td>
<td></td>
</tr>
<tr>
<td>SunD-5: The earth revolves around the sun to bring the sun back into our sky.</td>
<td></td>
</tr>
<tr>
<td>SunD-6: The sun and moon switch places.</td>
<td></td>
</tr>
<tr>
<td>SunD-7: The sun comes down from space.</td>
<td></td>
</tr>
<tr>
<td>SunD-8: The student does not know or the answer is unclear.</td>
<td></td>
</tr>
</tbody>
</table>

Theme 9: Comparison of the disappearance of the sun and moon

One category was used to compare the students’ explanations for the disappearance of the sun and moon from the sky: SuMo. This category included codes that described whether they used the same or different explanations. Coding was based primarily on their verbal responses though some students chose a visual demonstration as well, such as pointing down or showing the sun rising up into the dome/sky. The codes were not assigned accuracy levels because this category was not used in Part B.
Table 3.10 Codes developed for the comparison of the disappearance of the sun and moon

<table>
<thead>
<tr>
<th>Category</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SuMo:</strong> Does the student use the same explanation for why we can’t see the sun at night and why we cannot always see the moon?</td>
<td>SuMo-1: Uses same explanation or description. SuMo-2: Uses different explanations or descriptions. SuMo-3: Answers are unclear or unknown.</td>
</tr>
</tbody>
</table>

Study A

The first and second research questions were answered together for each theme. The analysis performed to answer these questions was based directly on the coding of each of the categories described above. For each theme, I described how the students expressed their ideas of celestial motion. Quotes from students were used to illustrate their ideas in each of the themes.

In Chapter 4, a series of tables list each category with their corresponding set of codes based on the student responses. The number of students in each grade level who were assigned to each code is then listed. The second research question was answered by examining the percentage of students in each grade level that exhibited different responses within each category to look for patterns. These patterns could take the form of either one age group exhibiting a tendency towards one particular description or a concept appearing at the same relative frequency across all age groups. Chi-square tests were performed to look for significance in the patterns observed across the age groups.
Study B

Each of the research questions that guided Study B was broken down into multiple sub-research questions. Analysis of the change in students’ responses from before to after the planetarium program in one or two categories was used to answer each of the sub-questions. The main research questions, sub-questions and codes used to answer each question are listed in Table 3.11.

Table 3.11 Research questions, sub-questions and supporting categories used in Study B

<table>
<thead>
<tr>
<th>Main research question</th>
<th>Sub-research question</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research question 1:</td>
<td>Do students demonstrate improved understanding of the apparent motion of the sun across the sky in summer?</td>
<td>Spath</td>
</tr>
<tr>
<td>Do students who participate in a kinesthetic learning program improve their knowledge of the patterns of motion of celestial objects by using kinesthetic learning techniques (KLTs)?</td>
<td></td>
<td>Szen</td>
</tr>
<tr>
<td>2.</td>
<td>Do the students demonstrate improved understanding of the apparent motion of the sun across the sky in winter?</td>
<td>Wpath</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wzen</td>
</tr>
<tr>
<td>3.</td>
<td>Do the students demonstrate improved understanding that the path of the sun is shorter and lower in the winter than the summer?</td>
<td>Clen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Calt</td>
</tr>
<tr>
<td>4.</td>
<td>Do the students demonstrate improved understanding of the apparent motion of the moon across the sky?</td>
<td>Mpath</td>
</tr>
<tr>
<td>5.</td>
<td>Do the students demonstrate improved understanding of the motion of the stars in the night sky?</td>
<td>MV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>StDif</td>
</tr>
<tr>
<td>Research question 2:</td>
<td>Do students demonstrate improved understanding of the concept that the appearance of the moon changes on the order of days or weeks?</td>
<td>Mapp</td>
</tr>
<tr>
<td>Did students learn about addition topics covered in the planetarium program that did not involve kinesthetic motion?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Do the students demonstrate improved understanding of the concept that the shape of the moon does not appear to change over the course of one night?</td>
<td>MCN</td>
</tr>
</tbody>
</table>
3. Do the students demonstrate improved knowledge of the moon’s appearance in the daytime sky? Mday

4. Do the students give improved explanations for the stars location during the day? StDay

Research question 3:
Are there other concepts, not linked to the main instruction of the planetarium program that also showed post-visit change?

1. Do the students demonstrate improved understanding of the location of the moon when we cannot see it? MoNV

2. Do the students demonstrate improved understanding of the location of the sun at night? SunN

3. Do the students demonstrate improved understanding of what happens to make it day? SunD

The interviews were coded following the scheme described above, just as in Study A. Each code was designated as accurate, partially accurate, or non-normative understanding of the category. This was done in order to assign a numeric value to each student’s level of understanding for statistical analysis. Accurate was designated as ‘3’, partially accurate as ‘2’ and non-normative as ‘1’, allowing the students’ responses to be represented by numbers that are ranked and ordinal. A student that changed from a non-normative to an accurate response has shown a greater improvement than a student that changed from a non-normative to partially accurate or a partially accurate to accurate response.

I have used the Wilcoxon matched-pairs signed-ranks test, designed to determine whether the distribution of scores from two correlated samples are significantly different. The samples are correlated because I am matching the pre- and post-instruction interview results for each student in each category. The Wilcoxon test “gives more weight to a pair
which shows a large difference between the two conditions than to a pair which shows a small difference” (Siegel, 1956). Thus a student who moves from non-normative (1) to accurate (3) is ranked higher than a student who only shifted from partially accurate (2) to accurate (3). One limitation of this type of analysis is that it does not consider the number of students who did not change their level of accuracy. It only compares the students who improved to those who regressed. To account for this, I also included cross tabulations that show the number of students who remained at the same level of accuracy. This allowed me to examine how much of an impact the planetarium program had on the entire group of students tested, not just those who improved and regressed.

I was also interested in examining whether certain student characteristics were possible confounding variables. First, I compared the students’ initial knowledge level with improvement for each topic. This was done to determine whether or not the planetarium program was only helpful for students who were already partially accurate, or if the program was equally useful in helping students who were non-normative and partially accurate improve their level of understanding. To make this comparison I used the Mann-Whitney $U$ test for non-parametric data. The Mann-Whitney $U$-test can be used to determine whether two uncorrelated means differ significantly from each other (Borg & Gall, 1989). Here, the two populations being compared are students who were initially non-normative versus students who were initially partially accurate, in a specific category. The null hypothesis states that the distribution of scores (improvement value) among both groups are identical. Because I was only interested in determining whether there was a difference between the tendency to improve in two groups (non-normative and partially accurate), not the amount of improvement, I set improvement equal to ‘1’,
no change equal to ‘0’ and regression equal to ‘-1’. Therefore, even if a student/improved from non-normative to accurate they were still assigned a value of ‘1’ for their
improvement as were students who moved from non-normative to partially accurate and
partially accurate to accurate.

The Mann-Whitney U-test was also used to determine whether gender, grade
level, or school was correlated with either the initial knowledge level or with
improvement for each category using the same improvement levels as defined above.

**Chapter Summary**

This chapter describes the methodology used to conduct two related studies of
children’s knowledge of celestial motion. In Study A, sixty children in first, third, and
eighth grade were interviewed using a protocol that allowed the students to express their
understanding both verbally and through demonstration. The results of these interviews
were then analyzed and coded to describe the nature of children’s ideas across a range of
topics. Analysis of the coded responses was then used to answer the research questions
posed in this study, which is described in Chapter 4.

Study B examined how students’ knowledge of apparent celestial motion changed
after participating in a planetarium program that involved kinesthetic learning techniques.
Sixty-three first- and second-grade students were interviewed before and after the
planetarium program using the same protocol as was developed for Study A. This
chapter describes the statistical tests used to determine whether changes in the students’
responses were significant. The analysis of this study is described in Chapter 5.
CHAPTER 4
CHILDREN’S UNDERSTANDING OF THE MOTION OF
CELESTIAL OBJECTS

Overview

The purpose of Study A was to describe students’ knowledge of the apparent motion of the sun, moon and stars, as seen from the earth and to examine how this knowledge changes from elementary through middle school. The results of this analysis will then be available to help researchers and curriculum developers address these and related topics in astronomy. This chapter describes the results of one-on-one interviews with groups of 20 first, third, and eighth grade students. These semi-structured interviews were analyzed to answer the following research questions:

1. What are students’ conceptions of the patterns of motion of the sun, moon, and stars, as viewed from the earth?
2. Do students’ conceptions of the motion of the sun, moon, and stars change with grade level?

The analysis of the interviews focused both on how the students demonstrated the apparent motion of the sun, moon and stars and their verbal descriptions of these motions.

The presentation of the results of this study begins with answering the research questions simultaneously. This is done by breaking down the patterns of celestial motion into the following themes:
• The apparent motion of the sun in summer
• The apparent motion of the sun in winter
• The seasonal comparison of the sun’s motion
• The actual motion of the sun
• The appearance of the moon
• The apparent motion of the moon
• The apparent motion of the stars
• Day and night
• Comparisons of the disappearance of the sun and moon

The students’ answers to questions regarding each of these themes have been analyzed and grouped into categories in order to characterize the nature of the students’ understanding of apparent celestial motion. The coding scheme was developed from the students’ responses in each category. Each student’s answers for each category have been coded using a scheme as one of a list of possible student responses seen across the interviews. The codes describe each of the ways that the students described and demonstrated their answers to the interview questions. The list of categories and frequency of each code are broken down by grade-level in Tables 4.1 through 4.9. Codes are ordered with the most accurate responses listed at the top. These results are further described to bring out interesting patterns that appear in the students’ answers and illustrated with students’ verbal responses.

Students’ understanding of patterns of celestial motion

Theme 1: The apparent motion of the sun in summer

The first part of the interview consisted of questions designed to help the students demonstrate their understanding of the apparent motion of the sun in the summertime. To demonstrate an accurate path for the sun, the student would need to show a smooth curve that does not pass through the zenith, and a setting position that is more than 45
degrees from where it rose. Thus an accurate path is not necessarily an exact replication of the sun’s actual path as seen from the student’s current latitude. In the process of assessing the student’s knowledge of the path of the sun, their ideas about the timing and location of the sun’s highest altitude were also assessed. The interviews revealed that not all children believe that the sun moves continuously across the sky. Table 4.1 shows the results of analyzing the students’ knowledge of the apparent motion of the sun in summer.

Apparent path of the sun in summer

The results displayed in Table 4.1 show that there is a shift in how students describe the apparent path of the sun in summer across the grade levels. There is a statistically significant increase across the grades in the number of students who chose the partially accurate path (a smooth curve across the sky passing directly overhead), $\chi^2 (2, N = 60) = 17.42, p<0.001$. The first grade students primarily demonstrated one of three different paths: the partially accurate path (25%), a path where the sun rose and set in approximately the same location (25%) or a path that included multiple inaccuracies compared to the actual path of the sun (35%). The majority of third grade students demonstrated the sun’s path as a smooth curve through the zenith (60%), though a sizable fraction indicated that the sun rises and sets in the same location (25%). The same percentage of students in the first and third grade believed that the sun rises and sets in the same location. The eighth grade students primarily demonstrated that the sun’s path is a straight path through the zenith (90%). One of the eighth grade students demonstrated the accurate path of the sun.
Table 4.1 The apparent motion of the sun in summer

<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Grade level</th>
<th>First</th>
<th>Third</th>
<th>Eighth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the path of the sun accurate? (Spath)</td>
<td>1. Smooth path, not through the zenith</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>(5%)</td>
</tr>
<tr>
<td></td>
<td>2. Smooth path, through the zenith</td>
<td>5 (25%)</td>
<td>12 (60%)</td>
<td>18a (90%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Path that includes rising and setting but also other inaccuracies</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>(5%)</td>
</tr>
<tr>
<td></td>
<td>4. Sharp turn in the middle of the path</td>
<td>1 (5%)</td>
<td>1(5%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. No resemblance to actual path</td>
<td>7 (35%)</td>
<td>1 (5%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Rise and set position within 45 degrees</td>
<td>5 (25%)</td>
<td>5 (25%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Shows more than one path</td>
<td>2b (10%)</td>
<td>1c (5%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Is the sun below the zenith at its highest point? (Szen)</td>
<td>1. Below the zenith</td>
<td>0</td>
<td>4 (20%)</td>
<td>2 (10%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Inconsistent: Indicates both that sun is below zenith but also that it goes through the zenith</td>
<td>5 (25%)</td>
<td>1 (5%)</td>
<td>5 (25%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Through the zenith</td>
<td>15 (75%)</td>
<td>15 (75%)</td>
<td>13 (65%)</td>
<td></td>
</tr>
<tr>
<td>Is the sun highest at noon? (Snoon)</td>
<td>1. Highest at noon</td>
<td>5 (25%)</td>
<td>13 (65%)</td>
<td>16 (80%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Inconsistent</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>(5%)</td>
</tr>
<tr>
<td></td>
<td>3. Highest at some other time of day</td>
<td>7 (35%)</td>
<td>4 (20%)</td>
<td>3 (15%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Sun at same altitude for more than one time of day</td>
<td>7 (35%)</td>
<td>2 (10%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Unknown</td>
<td>1 (5%)</td>
<td>1 (5%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Is the sun’s motion continuous? (Scon)</td>
<td>1. Yes, sun moves continuously across the sky</td>
<td>12 (60%)</td>
<td>18 (90%)</td>
<td>19 (95%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. No, Sun stops moving for periods of time</td>
<td>8 (40%)</td>
<td>2 (10%)</td>
<td>1</td>
<td>(5%)</td>
</tr>
</tbody>
</table>

a Marina initially showed an irregular path but then clarified herself saying “I did it the wrong way.”
b Both Cecelia and Bobby initially showed paths with no simple pattern (no resemblance to the actual path) but then later showed a path where the sun rose and set in about the same place on the horizon.
c Andrea showed an accurate path initially but later she showed the sun passing through the zenith.

The eighth grade students were also more likely than the younger students to mention directions (east or west) when describing the rising and setting of the sun, $\chi^2 (2,$
$N = 60) = 32.87, p < 0.001$. The students were not specifically asked to indicate direction; they volunteered this information. Sixteen of the eighth grade students (80%) indicated the direction that the sun rose in (most said east but a few specifically said the sun rises in the west). Five of the third grade students (25%) and none of the first grade students mentioned that the sun rises in the east.

A large fraction of both the first and the third grade students, but not the eighth grade students, demonstrated that the sun rises straight up to the zenith and then sets within 45 degrees of where it rose. An additional two first grade students were coded as demonstrating two different paths for the sun that were also similar to this “straight-up-and-down” description of the sun’s apparent motion. A few students demonstrated the path of the sun differently when asked to first, point out where the sun is at specific times of day and second, demonstrate what the sun does throughout the entire day. When asked to show where the sun was at different times of day, the two first grade students both demonstrated paths that were not similar to the actual path of the sun. For example, Bobby\(^7\) started with the sun at the zenith, then showed it moving down, then back up. When asked to show what the sun does for the entire day, both of these students showed the path of the sun moving up and back down along the same path, so that the rise and set positions were identical. Students with this “straight-up-and-down” belief about the sun’s motion have not yet had enough experience with the world to realize that the sun rises and sets on opposite sides of the sky, or have not yet developed a sense of direction that would allow them to learn the correct description on their own.

\(^7\) All names of persons, institutions and locations are pseudonyms.
Seven of the first grade students and one of the third grade students demonstrated a path for the summer sun that was not as similar to the actual path of the sun as the paths described above. This was the most frequent response coded for the group of first grade students (35%). The students coded with this response gave the following descriptions of the sun’s apparent motion:

- Three students demonstrated that the sun begins the day at the top of the sky and remains there until the end of the day (Seth, Toby, and the third grade student, Sally). Similarly, Belinda showed the sun start the day near the zenith, circle around the zenith during the day, and then set at the end of the day.
- Abigail demonstrated that the sun rises straight up to the zenith, moves back and forth around the zenith during the day, and then sets straight down.
- Alicia demonstrated that the sun moves through the zenith to the opposite side of the sky and then return back along the same path to set near where it rose.
- James demonstrated that the sun rises up, moves back down, rises up again, and then sets where it rose.
- Bridgette was unable to demonstrate the path of the sun:

  Interviewer: If that’s the sky up there (I pointed to the dome) where will the sun be (at lunchtime, implied from previous questions)?
  Bridgette: Behind the clouds.
  I: What if there weren’t any clouds? Where would you see it?
  Bridgette: Everywhere. (She points around the middle of the sky.)
  I: How about the afternoon? Where’s the sun when school gets out?
  Bridgette: Uhm, up in the sky.
  I: What happens to sun at end of day?
  Bridgette: Goes down. (She shows the sun going straight down to the horizon.)

**Altitude of the sun when it’s highest in the sky**

Almost all of the students interviewed at each grade level believe that the sun passes directly overhead in the summer. There was no significant difference in the number of students who held this belief between first, third, and eighth grade students, $\chi^2(2, N = 60) = 0.66, p>0.05$. The coding for this was based both on where they pointed to in the dome and their answer to the question “Would that be directly over our heads?” It
was important to check for this concept both visually and verbally because when sitting in the dome the top of the dome is not directly overhead. Only two eighth grade students and four third grade students accurately indicated that the sun does not pass through the zenith. Only one of the eight grade students, and none in third, also demonstrated an accurate path of the sun. The other eighth grade student indicated that the sun does not move continuously across the sky. The four students in third grade who indicated that the sun remains below the zenith also had other inaccuracies in their responses concerning the apparent path of the sun. One student demonstrated a path with multiple sharp turns. The other three students demonstrated paths that showed the sun rising and setting in nearly the same place.

There was a split in the distribution of students who were coded as “inconsistent” in their response to this topic: five students in both the first and eighth grades, but only one of the third grade students. Three different types of responses were coded as inconsistent:

- Four of the first grade students and four of the eighth grade students first demonstrated a path that showed the sun going through the zenith and then also pointed at the zenith when asked to point at where the sun is when it is highest. But these students also responded negatively when asked if that was directly overhead.
- One third grade student and one eighth grade student demonstrated a path that showed the sun passing through the zenith. However, when they asked where the sun was at its highest pointed to a position below the zenith. They also verbally confirmed that this was not directly overhead.
- One first grade student pointed below the zenith as the sun’s highest position, but said this was directly overhead.

Perhaps those students who indicated that the sun is not overhead when it appears highest in the sky but demonstrated otherwise have learned that the sun is not directly over head at its highest point, but do not have enough experience thinking about the how to explain
the apparent motion of the sun to demonstrate both their idea of the path and their knowledge of the sun’s altitude accurately. This seems to be a more reasonable explanation for the inconsistency in the eighth grade students’ answers than the first grade students’ answers because the younger students are less likely to have learned about the sun’s altitude in school, or other situations, because of their age. Another possible explanation is that the students did not believe that “directly overhead” is the same thing as the middle of the sky.

**Sun’s altitude at noon**

I also examined the students’ knowledge of where the sun is located at specific times of day. I asked the students to point to where the sun was first thing in the morning, at 10 o’clock, at noon and in the afternoon when school gets out. There was a significant increase in the number of students at each grade level who knew that the sun is highest in the middle of the day, $\chi^2 (2, N = 60) = 11.31, p<0.01$. Only 25% of the first grade students gave an accurate response compared to 65% of the third grade students and 80% of the eighth grade students.

There were two alternative ideas expressed about the sun’s highest altitude, more common among the younger students. The first alternative idea was that the sun is highest in the sky at a time other than noon. This concept was more prevalent among the first grade students (35%) than the third and eighth grade students (20% and 15%, respectively). The second alternative idea was expressed by students who demonstrated a path where the sun either passed through it’s highest point at multiple times during the day or remained at the zenith throughout a portion of the day. Students coded with this
response were primarily those first and third grade students who demonstrated paths that did not closely resemble the actual path of the sun.

**Uniformity of motion**

Although most students demonstrated that the sun appears to move slowly and continuously across the sky during the day, some students indicated that it remains in one place for part of the day. I did not specifically ask the students whether or not they believe that the sun’s motion is continuous; this concept was coded based on how the students described path of the sun throughout the day. Significantly more of the first grade students, compared to the older students, indicated that the sun’s apparent motion is not continuous, \( \chi^2 (2, N = 60) = 9.57, p<0.01 \). Seven of the first grade and one of the third grade students described the sun as remaining at the zenith for all or part of the day. One additional third grade student showed the sun remaining at about 75 degrees during the middle of the day. These students gave a range of descriptions of the path of the sun: a straight line through the zenith (two in first grade), rising and setting in the same place (two in first grade), starting at the zenith and staying there until the sun sets at night (two in first and one in third grade) and one student that showed the sun remaining at the zenith from noon through the afternoon but was not consistent in whether the sun begins at the zenith or the horizon. One additional first grade student, Bridgette, was coded as not showing continuous motion. When I asked her where the sun is at lunchtime she said “everywhere” and pointed around the top of the sky. She said that the sun was “up in the sky” when school gets out.” Her answer does not clearly state that the sun remains apparently motionless in the sky, but she does seem to lack the ability to describe the sun’s apparent motion as a continuous path. Rick, an eighth grade student also indicated
that the sun’s motion is not continuous throughout the day. He described the sun’s apparent motion throughout the day: “It starts going up and it comes up to its peak and then it stays up there until about 5 o’clock and it starts coming down, and the sun starts going down and the moon comes up.”

**Summary: The apparent motion of the sun in summer**

The students demonstrated a wide range of ideas concerning the nature of the sun’s path across the sky. There is a change across grade levels in how students typically describe the path of the sun. Nearly all eighth grade students demonstrated a partially accurate path for the sun in summer. In contrast, only a quarter of first grade students and slightly more than half of the third grade students demonstrated this level of accuracy for the path of the sun. The first grade students were more likely to either describe the sun’s apparent motion without the concept of ‘rising and setting’ or to suggest that the sun rises and sets in the same place on the horizon.

Most of the students hold the alternative idea that the sun passes directly over head during the summer. There is no significant change in the large percentage of students who hold this belief across the grade levels. However, there is a significant change in the students’ knowledge of when the sun is highest in the sky. Few of the first grade students knew that the sun is only at its highest at noon (though several indicated that the sun is highest at noon as well as for the rest of the day). More than half of the third grade students and over three-quarters of the eighth grade students have reached the accurate understanding that the sun is highest at mid-day.

Finally, a significantly greater fraction of the first grade students believe that the sun does not move continuously throughout the day compared to students in third and in
eighth grades. This suggests that most students have learned that the sun moves continuously across the sky before third grade, even if they have not learned the accurate description of the sun’s path.

**Theme 2: The apparent motion of the sun in winter**

The students were asked the same questions about the sun’s path in winter as they were asked about the sun in summer. The results are shown in Table 3.2.

**Table 4.2 The apparent motion of the sun in winter**

<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Grade level</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the path of the sun accurate? (Wpath)</td>
<td>1. Smooth path, not through the zenith</td>
<td>First</td>
<td>0</td>
<td>2 (10%)</td>
<td>2 (10%)</td>
</tr>
<tr>
<td></td>
<td>2. Smooth path, through the zenith</td>
<td>Third</td>
<td>3 (15%)</td>
<td>12 (60%)</td>
<td>16 (80%)</td>
</tr>
<tr>
<td></td>
<td>3. Path that includes rising and setting but also other inaccuracies</td>
<td>Eighth</td>
<td>0</td>
<td>0</td>
<td>1 (5%)</td>
</tr>
<tr>
<td></td>
<td>4. Sharp turn in the middle of the path</td>
<td></td>
<td>1 (5%)</td>
<td>1 (5%)</td>
<td>1 (5%)</td>
</tr>
<tr>
<td></td>
<td>5. Rise and set position within 45 degrees</td>
<td></td>
<td>11 (65%)</td>
<td>3 (15%)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>6. No resemblance to actual path</td>
<td></td>
<td>5 (25%)</td>
<td>1 (5%)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>7. Shows more than one path</td>
<td></td>
<td>0</td>
<td>1 (5%)</td>
<td>0</td>
</tr>
<tr>
<td>Is the sun below the zenith at its highest point? (Wzen)</td>
<td>1. Below the zenith</td>
<td></td>
<td>3 (15%)</td>
<td>6 (30%)</td>
<td>3 (15%)</td>
</tr>
<tr>
<td></td>
<td>2. Inconsistent: Indicates both that sun is below zenith but also that it goes through the zenith</td>
<td></td>
<td>2 (10%)</td>
<td>3 (15%)</td>
<td>4 (20%)</td>
</tr>
<tr>
<td></td>
<td>3. Through the zenith</td>
<td></td>
<td>13 (65%)</td>
<td>11 (55%)</td>
<td>13 (65%)</td>
</tr>
<tr>
<td></td>
<td>4. Unknown</td>
<td></td>
<td>2 (10%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Is the sun highest at noon? (Wnoon)</td>
<td>1. Highest at noon</td>
<td></td>
<td>9 (45%)</td>
<td>7 (35%)</td>
<td>12 (60%)</td>
</tr>
<tr>
<td></td>
<td>2. Inconsistent</td>
<td></td>
<td>0</td>
<td>1 (5%)</td>
<td>2 (10%)</td>
</tr>
<tr>
<td></td>
<td>3. Highest at some other time of day</td>
<td></td>
<td>4 (20%)</td>
<td>11 (55%)</td>
<td>5 (25%)</td>
</tr>
<tr>
<td></td>
<td>4. Sun at same altitude for more than one time of day</td>
<td></td>
<td>4 (20%)</td>
<td>1 (5%)</td>
<td>1 (4%)</td>
</tr>
<tr>
<td>5. Unknown</td>
<td>3 (15%)</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>--------</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is the sun’s motion uniform? (Wcon)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Sun moves continuously across the sky</td>
<td>13 (65%)</td>
<td>18 (90%)</td>
<td>20 (100%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Sun stops moving for periods of time</td>
<td>7 (35%)</td>
<td>2 (10%)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Overall, a similar pattern of responses was seen in the students’ description of the sun’s apparent motion in winter as was seen in the summer interviews, with a few exceptions. Rather than going over the responses in detail again, I will highlight some of the interesting similarities and differences in the student’s responses in winter compared to summer. However the students’ knowledge of the difference in the sun’s path in summer and winter, at the individual level, will be discussed in the section on Theme 3.

**Apparent path of the sun in winter**

There was a small increase in the number of students who demonstrated an accurate path for the sun in winter. In summer, only one student demonstrated an accurate path in summer while in winter there were four coded as accurate (two in both third and eighth grade). Diane, one of the third grade students coded as accurate, demonstrated the sun’s path as straight through the zenith in the summer, and passing through a much lower altitude in the winter. When asked how the winter is different from the summer she says: “Because usually it goes straight up and then comes down in the summer. But this kinda goes to the side.” However, she also demonstrated that the sun moves in the opposite direction in the winter compared to the summer. Kerrie, an eighth grade student, also demonstrated the accurate path of the sun:

I: Where is the sun when it's highest in the sky?
Kerrie: Up at noon? (Points to 75 deg altitude)
I: Is that the same as it was in the summer?

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8 This is discussed in Theme 3: Comparison of the sun’s path across the seasons
Kerrie: Uh, maybe a little different. Maybe like a little bit lower, since we're like angled away from the sun.

Marina, the other accurate eighth grade student, described the high point of the sun: "I think in the winter it's like right, it's not totally up there. It's to the side a little." But she also showed the sun moving in the opposite direction in winter compared to the summer.

A larger portion of the first grade students showed the sun rising straight up and setting in the same place in winter compared to summer, increasing from 5 (25%) students to 11 (55%) students. The five students who initially demonstrated that path in summer demonstrated that same path in winter. Another five students demonstrated paths in summer that did not include the simple motion of rising and setting: the sun at or near the zenith during most of the day (three students), moving up and down twice during the day (one student), and two different non-normative paths (one student). The sixth student showed the sun making a straight line through the zenith in summer.

**Altitude of the sun when it’s highest in the sky and the sun’s altitude at noon**

More students demonstrated that the sun does not pass through the zenith in winter (20%) than in summer (10%). This difference is smaller if we include the students who were inconsistent as understanding that the sun does not pass through the zenith (35% in winter compared to 28% summer). It is interesting that the number of students who knew that the sun does not pass through the zenith peaked among the third grade students (30%); only 15% of the first and eighth grade students were accurate on this topic. However, this does not consider that fact that overall the eighth grade students were demonstrating more accurate paths than the younger students.
There is a more noticeable shift in the number of students at each grade who indicated that the sun is highest at noon in winter compared to summer. More of the first grade students indicate that the sun is highest at noon in winter (45%) compared to summer (25%). This was coupled with a decrease in the number of students who said the sun was highest at some other time of day (20% versus 35%). The opposite pattern occurred among the older children. The percentage of students in third and eighth grade who said that the sun is highest at noon dropped in winter (40% in third, 60% in eighth) compared to summer (65% in third, 80% in eighth). There was also an increase in the number of students who think the sun is highest at another time of day in winter (55% in third; 25% in eighth) compared to summer (20% in third; 15% in summer). This suggests that some students believe that the time that the sun reaches its highest altitude depends on the season. The shift that occurred in the older students may indicate that these students are influenced by the change in the amount of daylight in winter compared to summer and are attempting to explain this by shifting when the sun appears highest. They may also be influenced by the fact that the sun sets earlier in winter or even Daylight Savings Time. Another possible explanation for the shift in demonstrations of the timing of the sun’s highest altitude would be that some students do not know how to express the change in seasons and are just trying to indicate some type of difference.

**Uniformity of motion**

There was essentially no change in the number of students who indicated that the sun’s motion is not continuous and uniform in winter compared to summer. The number of first grade students who had alternative ideas about the uniformity of the sun’s motion stayed the same (35% in each season). The number of third and eighth grade students
who had an alternative idea about the uniformity of the sun’s motion only shifted by one student (third grade: increased from one (5%) in summer to two (10%) in winter; eighth grade decreased from one (5%) in summer to zero in winter). However, not all of the seven students in first grade who indicated that the sun does not move continuously during the summer also indicated this idea in winter. There are four students who only indicated the sun does not move continuously in winter and four who only indicated in summer. This brings the total number of first grade students who indicated in summer or winter that the sun does not move continuously to 11 (55% of all first grade students).

Similarly, the third grade student who indicated that the sun does move continuously in summer was not one of the two students who mentioned this idea in winter.

Not all of the students who were coded as non-normative did so by indicating the sun remains fixed in one location. The two students in third grade coded as non-normative for this topic in winter did so by suggesting that the sun must move faster in winter in order for the days to be shorter. Lana explains that the change in the speed of the sun’s motion is due to the earth’s motion:

I: How high will the sun get?
Lana points to zenith.
I: Same as summer?
Lana: Uh, not exactly.
I: How is it different?
Lana: Because in summer it’s a longer day so it would be more up because it the sun can’t go too fast or the day would be shorter. But if the day was shorter here it could be going a little faster.
I: When it’s shorter the sun’s moving faster?
Lana: <***> the world.
I: Oh the world. Does the sun seem to be moving across the sky faster?
Lana: Yeah.

---

9 <*>: A short unintelligible utterance; <***>: A longer unintelligible utterance or phrase.
Nick also indicates a change in the sun’s apparent speed across the sky but this change occurs across one day not the seasons:

Nick: The days are shorter <*> it moves faster in the afternoon because it like in the morning it goes uhm quicker but like it goes in the afternoon it goes like it goes quicker.
I: In the afternoon it goes quicker?
Nick: It goes quicker than in the morning.
I: So in the morning the sun is moving slower?
Nick: Yeah, because afternoon it goes quicker because uhm it’s moving faster because the orbits rotating faster because uhm because the days are shorter so it goes sooner in the afternoon.

Both Lana and Nick indicate that they know the days are shorter in winter compared to summer. Both of the students demonstrated that the sun follows the same path across the sky in summer and winter, with no change in length or altitude. Because they are unaware of the difference in the sun’s path between summer and winter they have explained the difference in a way that is consistent with their knowledge of the changing length of daylight and assumption about the nature of the sun’s path.

**Summary: Apparent motion of the sun in winter**

The results from analyzing the students’ understanding of the apparent motion of the sun in winter were very similar to the results from summer, with a few small differences. More students recognized that the sun does not pass through the zenith in winter than in summer, resulting in a small increase in the number of students categorized with an accurate path of the sun. There was also an increase in the number of first grade students who believe the sun rises and sets in the same section of the horizon, rather than moving across the sky. The shift was primarily from students who had demonstrated paths that were even less like the sun’s actual path in summer. Another change was the increase in the number of students who believe that the sun is highest in the sky at a time
other than the middle of the day. This may be in response to students attempting to indicate the difference between summer and winter. Several students described the sun’s motion as discontinuous in the winter, including additional students who did not exhibit this concept in the summer.

Theme 3: The seasonal comparison of the sun’s apparent motion

The distribution of the individual students’ understanding the change in the sun’s path between summer and winter is given in Table 4.3. Some comparisons between the students’ answers were made in the previous section. This section will focus primarily on the differences that influence the change in seasons. For northern hemisphere observers, the sun appears to be much higher in the southern sky in the summer and it covers a longer path across the sky than in the winter. These differences also lead to longer days.

The students were not specifically asked to compare the path of the sun in the summer and winter. They were asked explicitly whether the sun’s highest position in winter is the same as it was in summer. If they said it was different, they were asked to elaborate on how it is different. The rest of the comparisons were coded based on how the students demonstrated the path of the sun in summer and winter.
Table 4.3 The seasonal comparison of the sun’s apparent motion

<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Grade Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the student show the same path in summer and winter? (Cpath)</td>
<td></td>
<td>First</td>
</tr>
<tr>
<td>1. The path is the same</td>
<td>12 (60%)</td>
<td>15 (75%)</td>
</tr>
<tr>
<td>2. Paths are similar</td>
<td>3 (15%)</td>
<td>3 (15%)</td>
</tr>
<tr>
<td>3. Paths are not the same</td>
<td>5 (25%)</td>
<td>2 (10%)</td>
</tr>
<tr>
<td>Is the direction of the sun’s motion the same in summer and winter? (Cdir)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Same direction</td>
<td>4 (20%)</td>
<td>12 (60%)</td>
</tr>
<tr>
<td>2. Opposite direction</td>
<td>0</td>
<td>1 (10%)</td>
</tr>
<tr>
<td>3. Shifted by more than 45 degrees</td>
<td>0</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>4. Not comparable</td>
<td>16 (80%)</td>
<td>5 (25%)</td>
</tr>
<tr>
<td>Is the length of the sun’s path shorter in winter compared to summer? (Clen)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Rise and set positions are more than 45 degrees closer in winter</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>compared to summer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. No significant difference in length (sun rises and sets within 45</td>
<td>5 (25%)</td>
<td>13 (65%)</td>
</tr>
<tr>
<td>degrees)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Path of sun longer in winter compared to summer</td>
<td>1 (5%)</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>4. Paths are not comparable</td>
<td>14 (70%)</td>
<td>5 (25%)</td>
</tr>
<tr>
<td>Is the sun’s altitude lower in winter compared to summer? (Calt)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Sun’s altitude is lower in winter compared to summer</td>
<td>2 (10%)</td>
<td>4 (20%)</td>
</tr>
<tr>
<td>2. Indicates altitude is lower but does not demonstrate accurately</td>
<td>2 (10%)a</td>
<td>4 (20%)</td>
</tr>
<tr>
<td>3. Same noontime altitude</td>
<td>10 (50%)</td>
<td>10 (50%)</td>
</tr>
<tr>
<td>4. Reaches same altitude in summer and winter, but at different times</td>
<td>4 (20%)</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>5. Altitude is higher in winter</td>
<td>1 (5%)</td>
<td>0</td>
</tr>
<tr>
<td>6. Not enough information</td>
<td>1 (5%)</td>
<td>1 (5%)</td>
</tr>
</tbody>
</table>

*a One student demonstrated accurately that the sun appears lower in the sky in winter compared to summer but said that both positions were the same.
Comparing the type of path in summer to winter

The majority of students were consistent in using the same type of path in summer and winter (60% of first grade students and 75% of both third and eighth grade students), with no significant differences between the three grade levels, \( \chi^2 (1, N = 60) = 1.53, p > 0.05 \). Most of the remaining students in third and eighth grade showed similar paths but contained inconsistencies such as a change in the direction of the sun’s motion. More of the first grade students demonstrated completely different paths in summer and winter (25%) than the older students (10% in third and none of the eighth grade students). One first grade student indicated that the sun is not in the sky during the winter and two others were unable to show the sun’s motion throughout an entire day in the summer.

Direction of sun’s path

The students were not specifically asked about the direction that the sun rises or sets in. However sixteen of the eighth grade students (80%) volunteered the direction of where the sun rises in the summer. Fourteen of these students said that the sun rises in the east and two said that the sun rises in the west. Five of the third grade students mentioned that the sun rises in the East. None of the first grade students mentioned directions in their interviews.

The first grade students primarily demonstrated that path of the sun and winter in ways that were not directionally comparable (80% of the students). Paths that are “directionally comparable” rise on one side of the sky and set on the opposite side. The rest showed the sun moving in the same direction in both summer and winter. Most of the third grade students demonstrated the sun moving in the same direction in summer and winter (60%) or demonstrated paths that are not comparable (25%). A few students
also showed the sun moving in the opposite, or nearly opposite, direction in summer compared to winter (15%). All of the eighth grade students demonstrated paths that crossed the sky in both summer and winter, allowing the direction of the paths to be compared. The majority of eighth grade students indicated that the sun moves in the same direction in both seasons (80%). The remaining either demonstrated the sun moving in the opposite direction (3 students) or shifted by 90 degrees (1 student).

The shift in how the students demonstrated the direction of the sun’s path occurred in two ways. First, there was an increase in the percentage of students who demonstrated paths that were directionally comparable. This corresponded with the increase in the percentage of students who described the sun as moving in the same direction in summer and winter. The same percentage of students in third and eighth grade demonstrated that the sun moves in the opposite direction in summer and winter, with an additional eighth grade student showing the motion shifted by 90 degrees. None of the first grade students showed the sun moving in the opposite or a shifted direction. This is not surprising because only four of the students demonstrated paths in the summer and winter that could be compared.

Comparing the length of the sun’s path and altitude between summer and winter

In latitudes outside of the earth’s equatorial region (such as the location these interviews took place) the sun’s path in summer is significantly longer in summer compared to winter. In coding the interviews, I first looked in general at the length of the paths the students demonstrated based on the distance, measured in degrees, around the horizon from the rise to the set position. For a student to be coded as demonstrating a
difference in path length they must have shown the difference in rise and set positions between summer and winter to be greater than 45 degrees.

None of the students demonstrated knowledge of this difference. The first grade students were split between demonstrating paths that were no different in length and paths that were not comparable in length. Paths that were not comparable included showing the sun rising and setting in the same place, paths where the sun did not rise and/or set, or they showed different types of paths in the two seasons. The majority of both the third (65%) and eighth grade students (95%) showed paths of the same length.

The majority of the students interviewed believe there is no difference in the sun’s highest altitude between summer and winter. A correct demonstration of this idea was to show the sun lower in winter compared to summer and to verbally agree that the sun appears lower. Only ten percent of the first grade students gave an accurate comparison both in their demonstration and verbal description. Half (50%) of the students in the first grade indicated that the sun is at the same altitude in summer and winter at the same time. Another 20% of the first grade students indicated that the sun reaches the same altitude in summer and winter but at different times of day. Another 10% gave an inconsistent response. One of the first grade students accurately demonstrated that the sun is lower in winter but verbally expressed that they were the same altitude. The other first grade student was unable to show a path for the sun in winter (claiming that the sun is not in the sky in winter) but verbally agreed that the sun is lower in winter.

Only 20% of the third grade students accurate demonstrated that the sun is lower in winter than summer. Half of the third grade students demonstrated that the sun reaches
the same altitude at noon in summer and winter. Another 20% gave an inconsistent response that included either verbally or by demonstration, but not both, that the sun appears lower at noon in winter. The remaining two students indicated that the sun reaches the same altitude at different times of day or did not give enough information to be compared.

Only two of the eighth grade students gave an accurate demonstration and verbal response while one more student gave a partially accurate indication. Most of the eighth grade students indicated that the sun reaches the same altitude at noon (80%) or that the sun reaches the same altitude at different times of day (15%). Two of the eighth grade students attempted to use an alternative explanation to account for a difference between the sun’s appearance in the sky in summer and winter. Melanie demonstrated the same path for the sun in the summer and winter, from east to west, with one difference. The sun in winter is just at the edge of the area at the top of the dome around the zenith:

Melanie: A little over from the center. (She is describing the sun’s position when highest in the sky.)
I: How high will the sun get now that it’s winter?
Melanie: It will be closer to us, uhm, uhm, uhm, I’m not sure. It would be closer to us.
I: And as it appears in the sky? Where will it appear to be highest?
Melanie: <***>
I: Is that the same as it was in the summer?
Melanie: Uhm, yeah, but I think a little closer.

Robert demonstrates the same straight-line path through the zenith at noon in the summer and winter. He points to the zenith when asked where the sun is highest in the sky:

I: Is that the same as it was in the summer?
Robert: No.
I: How is it different?
Robert: Ah, uhm, the earth it is closer to the summer in the winter but its like turned away from it. It won't be as bright.
I: So if we looked for it in the sky would it be in the same place?
Robert: No.

Both students gave a version of the common alternative idea that the seasons are caused by a change in distance between the sun and earth, though Robert may also have shown some knowledge of the earth’s tilt in his response.

Returning to the eight students who were coded as accurately showing the sun’s altitude in winter as lower than summer, both eighth grade students and one of the third grade students were also coded as demonstrating an accurate path for the sun in winter (a smooth curve across the sky, not through the zenith). The remaining third grade students are also the three third grade students who demonstrated that the sun rises and sets in the same place both in summer and winter. Despite not knowing that the sun rises and sets on opposite sides of the sky they still indicated an accurate change in altitude of the sun. Neither of the first grade students who accurately demonstrated the difference in the sun’s altitude also showed an accurate or partially accurate path for the sun in both seasons.

**Summary: The seasonal comparison of the sun’s motion**

The majority of students interviewed demonstrated the same type of path in the summer and winter. Including students who believe that the sun rises and sets in a different direction across the seasons, this is 82% of all students interviewed. However, most of the students were either unaware or unable to demonstrate changes in length and altitude of the sun’s path between summer and winter. Most first grade students either showed no difference in the length of the sun’s path or did not show paths that were comparable. Most did not indicate any difference in the sun’s altitude in summer as well.
Most of the third and eighth grade students believe that the sun passes directly overhead in both summer and winter and that there is no significant in the difference in the length of the sun’s path. More of the third grade students gave some indication (either completely or partially) that the sun is lower in winter than in summer. One other interesting alternative idea observed was the concept that the sun’s motion switches directions in winter compared to summer. This was present in 15% of both the third and eighth grade students.

**Theme 4: The actual motion of the sun**

During the first segments of the interview, I asked the students questions about the sun’s apparent motion across the entire day. I then asked the students: “If you could see the actual sun out there in the sky, would it be moving across the sky right now?” This was asked to see how they would respond to thinking about the sun in immediate terms, rather over a long period of time (such as the length of the day). Table 4.4 shows the distribution of students’ ideas about the sun’s actual motion across the real sky.

<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Grade level</th>
</tr>
</thead>
</table>
| Is the sun actually moving in the sky outside right now? (Sacc) | 1. Sun doesn’t look like it is moving because it moves very slowly | First: 2 (10%)  
Third: 4 (20%)  
Eighth: 7 (35%) |
| 2. Sun does not appear to be moving because we are moving | 1 (5%)  
6 (30%)  
10 (50%) |
| 3. Sun does not appear to be moving because it is so far away | 0  
3 (15%)  
0 |
| 4. Sun appears to be moving because we are moving | 3 (15%)  
1 (5%)  
2 (10%) |
| 5. Unable to explain why sun does not appear to be moving | 8 (40%)  
3 (15%)  
1 (5%) |
| 6. Other                                           | 6 (30%)  
3 (15%)  
0 |
The most common response from the first grade students was that the sun does not appear to be moving in the sky but they were unable to explain why (40%). The rest of the first grade students gave a range of responses. Fifteen percent of the students said that the sun does not appear to be moving because either the sun or the earth is moving slowly. An equal number said that the sun would appear to move because we are moving. The remaining 30% of the first grade students had ideas that were not represented by more than one student and could not be easily grouped with motion of the sun or earth. This included the following:

- Sun appears to move but no explanation
- “It stays still” but no explanation
- Sun is not in the sky in the winter
- Demonstrates that the sun would look like it’s moving back and forth across the sky
- Seems to follow you when you run because it is so high
- “Cause sometimes when I get out I think it’s so bright because we were in the dark and now we’re in the light. So its kind of we don’t really know.”

Like the first grade students, the students in third grade also gave a range of answers though the third graders favored the concept that the sun would not appear to be moving because the sun is moving slowly (20%) or the earth is moving slowly (30%). Another 15% of the third grade students said that the sun does not appear to be moving because it is so far away. Three gave answers that did not match any other student’s answer:

- In the summer it would look like it is moving, because it is warm. In the winter it would not appear to be moving, because it is cold.
- Sun is not moving. “Because it’s daytime at night time it goes down.”
- Explanation was unclear but student indicated it would be moving “A little bit at a time.”
Fifteen percent of the third grade students could not explain why the sun does not appear to move in the sky. One student indicated that the sun would seem to be moving because we are moving.

Students in eighth grade primarily explained that the sun does not appear to be moving because the sun is moving very slowly (35%) or because of the slow motion of the earth (50%) makes it seem like the sun was standing still. There were also two students (10%) who suggested that the sun would appear to be moving because the earth is moving and one student who was not sure why the sun would not appear to be moving.

The major shift in the students’ understanding of this concept was towards an increasing number of students in the older grades who explained the sun’s apparent stillness by the sun or the earth’s slow motion. The younger students, especially those in first grade, were more likely than the older students to be unsure how to explain why the sun does not appear to move.

**Theme 5: Appearance of the moon**

I asked the students to first draw a picture of the moon and then I asked them if it ever appears different in the sky than in their drawing. This lead into questions about how long it takes for the shape of the moon to appear to change and whether or not we can see the moon in the sky during the daytime. Later, the students were asked where the moon is when we cannot see it in the sky. The students’ ideas and the frequency of responses are given in Table 4.5.
<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Grade level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Does the moon appear in the sky in different shapes?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Drawings include at least two accurate drawings of phases of the moon</td>
<td></td>
<td>15 (75%)</td>
</tr>
<tr>
<td>2. Unable to draw more than one shape for the moon or other inaccuracies</td>
<td></td>
<td>5 (25%)</td>
</tr>
<tr>
<td><strong>Does the appearance of the moon change on the order of days or up to a month?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Takes days for the appearance of moon to change</td>
<td></td>
<td>1 (5%)</td>
</tr>
<tr>
<td>2. It takes less than a night for significant change in the shape of the moon to be seen</td>
<td></td>
<td>11 (55%)</td>
</tr>
<tr>
<td>3. Takes well over a month for the appearance of the moon to change</td>
<td></td>
<td>1 (5%)</td>
</tr>
<tr>
<td>4. Moon’s appearance does not change</td>
<td></td>
<td>2 (10%)</td>
</tr>
<tr>
<td>5. Does not know</td>
<td></td>
<td>5 (25%)</td>
</tr>
<tr>
<td><strong>Does the shape of the moon appear to change over the course of one night?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. No visible change or change too small to notice</td>
<td></td>
<td>4 (20%)</td>
</tr>
<tr>
<td>2. Yes, the shape of the moon changes during the night</td>
<td></td>
<td>9 (45%)</td>
</tr>
<tr>
<td>3. Shape does not change</td>
<td></td>
<td>1 (5%)</td>
</tr>
<tr>
<td>4. Doesn’t know</td>
<td></td>
<td>3 (15%)</td>
</tr>
<tr>
<td><strong>Is the moon ever visible during the daytime?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Yes</td>
<td></td>
<td>9 (45%)</td>
</tr>
<tr>
<td>2. No, then changed their answer to “sometimes”</td>
<td></td>
<td>3 (15%)</td>
</tr>
<tr>
<td>3. No</td>
<td></td>
<td>8 (40%)</td>
</tr>
<tr>
<td><strong>Where is the moon when we can’t see it?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Moon is on the other side of the earth</td>
<td></td>
<td>2 (10%)</td>
</tr>
<tr>
<td>2. Moon is below the horizon</td>
<td></td>
<td>11 (55%)</td>
</tr>
<tr>
<td>3. Always in the sky but not always visible</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>4. Behind clouds</td>
<td></td>
<td>2 (10%)</td>
</tr>
<tr>
<td>5. Behind the sun</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
Knowledge of the phases of the moon

As part of describing children’s knowledge of the patterns of celestial motion, I was interested in their knowledge of how long it takes for the apparent phase of the moon to change. To do this I first asked the students to draw a picture of the moon for me. I then asked if the moon ever looked different. The vast majority were then able to draw with some level of accuracy another shape for the moon. For example, if they began by drawing a circle, they may have followed by drawing a crescent or a half-circle shape. Surprisingly, there were two eighth grade students, Robert and Jason, who did not draw or describe the phases of the moon.

Robert began by drawing a small circle with a small arc inside:

I: Does the moon always look like that in the sky?
Robert: Ah, yes.
I: OK, so we'd always see-
Robert: That one side of the moon, yes.
I: OK, would it always appear that same shape?
Robert: Uhm, yes.
I: Are there any ways that you notice the moon changes, as we see it?
Robert: Hmm, not really.

Even with probing, this student did not spontaneously describe the phases of the moon. It is possible that he did not understand the line of questions. Jason showed a similar lack of understanding of the phases of the moon, though again, he may not have understood questions. First, he drew a large circle.

Jason: I know every once and a while, not all the time, there's usually a crater kind of off-center a little bit, right of the telescope.
I: You look at the moon-
Jason: Not all of the time but every once in a while. And then my old friend had a Dad who, I don't know, he just like knew where every star was and when to look at it, what time of the day. Yeah, like every once in a while like, it'd be like at 4 o’clock and he'd be <***> be a star like <***> uhm, so.

I: So does the moon always look like that in the sky?

Jason: Sometimes it kinda, it just kinda looks bigger sometimes and sometimes smaller and then every once in a while it's either real, just kinda like fake-looking, like it's real orange, or-

I: Yeah, sometimes the color changes.

Jason: Actually looks like cheese <***>. (Laughs)

I: Does the shape of the moon ever change?

Jason: In the winter kinda it kinda does seem a little more like, like <*> ovalish.

I: Does it always appear circular in the sky?

Jason: Yeah.

I: Do you know anything about the phases of the moon?

Jason: A little bit but not very much.

I: Do you know what any of the phases are?

Jason: I couldn't say off hand, I don't think.

All of the third grade students interviewed were able to draw more than one accurate phase of the moon, but five of the first grade students had inaccuracies in completing this part of the interview. Two of the first graders were unable to describe more than one shape of the moon. For example, Seth compared the shape of the moon to the sun after drawing an oval shaped moon:

I: Does the moon always look like that in the sky?

Seth: Yeah, it it if the <*> shape like that.

I: Ah, so it’s the same shape as the sun?

Seth: Yeah

I: Does the moon change its shape during the night?

Seth: No it just goes, stays that shape.

I: Stays that same shape all the time?

Seth: That’s what sort of holds it…

I: Oh the sun is holding it in.

Seth: Yeah, holding it in.

The other three first grade students were able to draw more than one shape for the moon but these included some inaccuracies, such as drawing a “half moon” as a crescent
moon with a line bisecting it horizontally. Alicia indicated that we only see the full moon in the real sky and that crescent phase is seen in fairy tales:

I: I’d like you to draw a picture of the moon for me.
Alicia draws a full moon and a crescent moon.
Alicia: It can be two different ways.
I: Oh!
Alicia: In a fairy tale and real. (She points to the crescent and full moon, respectively.)
I: OK, so that’s real (pointing to the full moon) and –
Alicia: And that’s a fairy tale. Yeah, two different ways.
I: Do we see the moon in the sky both of those ways?
Alicia: This one would, this would be in the ah, the fairy tale. When they draw pictures of <***>. This would be here. In real life.
I: So in real life, does the moon change its shape in the sky?
Alicia: Hmm, no.
I: Why do they draw the moon different for fairy tales?
Alicia: Because some people don't know what the moon looks like sometimes.

While most students in first grade had some sense of the phases of the moon, there is still a large fraction of the students who were not able to describe the phases.

**Length of time for the shape of the moon to change its shape**

It takes approximately 28 days for the moon to move through a complete cycle of phases. In coding these interviews, I was not looking for whether or not the students knew the exact amount of time for the moon to complete one cycle. I coded for whether the student had a general sense of the amount of time for this change to occur. For this reason, I coded a student as accurate if they said that it took on the order of days for the moon to change from one shape to another (less than a day and more than a month were counted as non-normative). The students had previously drawn more than one phase of the moon (usually a crescent, quarter, and full) so I asked the how long it would take for the moon to change from one shape to another. I did so to make it clear that I was interested in large changes, not the small, incremental changes that do occur during the
length of a day. Then the students were asked whether they would notice any change during one night.

The first grade students primarily gave non-normative responses to these questions. About half of the students believe that the moon’s appearance can change from one phase to another in less than a day. Twenty-five percent of the first grade students were not sure how long it takes for the shape of the moon to change (though three of these later agreed that the moon’s shape would appear to change during a night). Only four of the first grade students (20%) accurately indicated that the moon’s appearance would not change, or only change very slightly, in less than a day. However, this included a student who believes it takes an entire year for the moon to go through phases, a student who could not draw more than just a circle for the moon, and a student who indicated that clouds are responsible for the changing shape of the moon.

The third grade students are nearly split between students who believe it takes less than a night to see significant change in the phase of the moon and those who gave a more accurate response. While most students simply responded that it takes “a month” or “a couple of days,” Lana gave an explanation for her accurate response:

Lana: Like what phase of the moon?
I: Any one that you want.
Lana draws a circle.
I: Does the shape of the moon ever look different?
Lana: It also looks like the half moon. And there’s a <*> crescent moon. And goes to a quarter moon.
Lana draws two “crescents” of different width and a half-moon.
Lana: There’s lots of ways that the moon <*>.
I: How long would it take to change from one shape to another?
Lana: Because the moon is turning around the earth it changes its phases and how often it’s a full moon about every month. It takes a month for it to turn around slowly.
I: Would its shape change during one night?
Lana: No

Jeremiah indicated that the moon shows different phases of the moon at different times of night.

I: How long does it take for the moon to change its shape?
Jeremiah: It takes about…. An hour.
I: Would you see its shape change during the night?
Jeremiah: A little bit.
I: Can we see the moon during the day?
Jeremiah: Yeah. When the sun is setting.
I: When the sun is setting?
Jeremiah: It’s just a quarter moon when the sun is setting.
I: When does the moon look like a circle?
Jeremiah: Full midnight.
I: When can we see the moon as you drew it in your picture (a half-moon)?
Jeremiah: <*> past sunset.

Another 20% of the third grade students initially did not have an answer to how long it takes for the shape of the moon to change. All of these students then agreed that the shape of the moon would change during a single night.

The majority of the eighth grade students (70%) understood the amount of time it takes for the shape of the moon to appear to change. Only three of the eighth grade students believed the appearance of the moon will change significantly in a single night, though there were also two eighth grade students who did not indicate that the shape of the moon ever changes (Robert and Jason).

The students’ understanding of this concept improved across grade levels. The most common alternative idea among the students was that the apparent shape of the moon changes significantly in less than a day. Some of this trend may be attributed to students who believe that the phases of the moon are caused by the movements of clouds.
in front of the moon (Baxter, 1989). This is seen in the following interview with a first grade girl, Marilyn:

I: Does the moon change its shape during the night?  
Marilyn: Well I think that when its crescent moon like this uhm that the cloud covers a little bit of it so <**>.  
I: So the reason it doesn’t look like this is because there are clouds covering it?  
Marilyn: Hmm (yes)  
I: So how long does it take it to change its shape?  
Marilyn: <***> clouds move.  
I: As long as it takes for the clouds to move? Alright.

Charles, a third grade student, also used clouds to explain the apparent change in the moon’s appearance.

**Moon during the daytime**

The students were asked whether or not we could see the moon during the daytime. Previous research in this area suggests that many young children believe the moon is only visible at night (Vosniou & Brewer, 1994). I found that most of the first grade students either knew the moon was visible during the day (45%) or first said it was not visible during the day and then changed their answer to sometimes (15%). Still, 40% of the first grade students did not know that the moon can be seen during the day. The majority of the third grade students also knew that the moon was visible during the daytime (60% said ‘yes’ plus 10% who indicated ‘no…sometimes’). There were still a quarter of the third grade students who did not know that the moon is visible during the day. All but one of the eighth grade students agreed that we can see the moon during the day.

There was an increase in the number of students who believe that the moon can be seen during the day from 60% of the first grade students up to 95% of the eighth grade
students. The younger students were also more likely to first say that we cannot see the moon during the day but then change their answer to sometimes (15% of first and 10% of third grade students). Perhaps these students still believe that the moon can only be seen at night but have also observed the moon around the time that the sun is rising or setting. Barbie, a first grade girl, answered: “Hmm-mmm (no), kinda, I don’t…. Yes, no, no. It mostly comes up at night. I used to see it in the morning because my parents go to work every morning.”

**Moon’s location when it is not visible**

In addition to asking the students about the patterns of motion and appearance of the moon, I also asked the students where the moon is when we cannot see it in the sky. This assesses whether the students know that the moon is on the other side of the earth or if they have an alternative explanation for the disappearance of the moon in the sky.

The first grade students gave a wide range of responses though most of the students indicated that the moon is down (55%) when we cannot see it. The students did not elaborate on what this meant; they said “down” or “under” or pointed down. These answers were similar to the students coded as saying the moon went ‘somewhere else’ such as “behind the hills” or “to another state.” First grade students also said that the moon is behind the clouds (10%) or on the other side of the world (10%). One student did not give an answer.

The third grade students also gave a wide range of responses. However, the most common response from these students was that the moon is on the other side of the earth (40%). Only one student said that the moon would go “down” and another said it would go “to another state”. The next most common response was that the moon would always
be in the sky but just not always visible (20%). Third grade students also said that the moon is covered by clouds (10%), is behind the sun (10%) and one student did not know.

The eighth grade students were split between two responses. The most popular was that the moon is on the other side of the earth (60%). Some of the students explained this using the rotation of the earth, such as in Darren’s response: “Ah, maybe the earth turned or something then we’re not facing the moon.” Other students, like Gretchen, just said “On the other side of the earth.” Almost all of the other eighth grade students indicated that the moon is always in the sky but that we cannot always see it (35%). The last eighth grade student did not know where the moon is when we cannot see it.

The alternative idea that the moon is always in the sky was more prevalent among the older children compared to the younger students. Seven of the eighth grade students and four of the third grade students were also coded with this concept (an additional two third grade students believed clouds are the reason we cannot always see the moon). None of the first grade students said that the moon is always in the sky although two indicated that the moon is not visible because the clouds are covering it. The students who believe the moon is always up the sky either indicated that this is because the sky is too bright during the day or that the alignment of the sun, earth and moon is not right for us to receive light from the moon (one eighth grade student did not give enough information to determine where his answer fit). Three of the third grade and three of the eighth grade students believed that the moon is not visible because the sky is too bright. This concept is typified by Sally’s response (a third grade student):

I: Where does the moon go when we can’t see it?
Sally: It’s still in the sky only can’t see it from the light.
I: Why can’t we see it?
Sally: Because at night time it’s dark and in the daytime there’s light out.
This concept seems to be a natural extension of these students’ observations of the world.

The second concept, held by three eighth grade students and one third grade student, that the moon is not getting light from the sun, may be related to the students’ attempts to learn concepts that explain the phases of the moon, such as in Jason’s response (eighth grade):

I: And if we didn't see it, why not?
Jason: Uhm, cause, the thing is, the sun's not in the right position. You can either see it or it's like behind it and you can't really see it."
I: Which is behind it?
Jason: Well, not like an eclipse or anything but like the sun, be on one side and the moon, you just wouldn't be able to see the moon. <*> reflection.
I: Would it still then be in the sky?
Jason: Yeah.
I: So is the moon always up there in the sky somewhere?
Jason: yeah
I: We just can't always see it?
Jason: Right.

Donald, a third grade boy indicated a similar idea, though with less detail:

I: Where does the moon go when we can’t see it?
Donald: It could really be anywhere, but the sun’s not shining on it.
I: Is it up there in the sky?
Donald: Yeah.

**Summary: Appearance of the moon**

A higher percentage of the older students were accurate in their understanding of how long it takes for the shape of the moon to appear to change. All but one of the first grade students held non-normative ideas about this concept. Only half of the third grade students gave an accurate response while nearly three-fourths of the eighth grade students indicated it takes days for the shape of the moon to change. The most common non-normative response among the first and third grade students is that the moon’s
appearance changes in less than a night. Most students at each grade level indicated that we can see the moon during the day this number did increase with the older students. The younger students primarily explained the disappearance of the moon from the sky as the moon either ‘down’ or behind something. I also found a range of responses from the third grade students however these students were more likely to say that the moon is on the other side of the earth than to indicate that the moon is ‘down’. The eighth grade students either indicated that the moon is on the other side of the earth when we cannot see it or that the moon is always in the sky but just not visible.

**Theme 6: Apparent path of the moon**

Table 4.6 shows the students’ responses to questions concerning the nature of path of the moon. The interview questions about the students’ knowledge of the apparent motion of the moon were set up in a similar manner to those asked about the path of the sun. Designing this portion of the interview was more challenging because the moon does not rise at the same time every day. I also did not want to lead the students to give answers that conformed to my knowledge of the moon’s apparent motion. For example, I did not want to ask them to show me how the moon rises and sets in case they did not believe that the moon moves (which turned out to be true for some students). A common alternative idea among young children is that the moon is only visible at night (Vosniadou & Brewer, 1994). Therefore, I asked them to imagine it was night-time and begin our discussion of the apparent motion of the moon by showing me where they might see the moon in the sky after the sun has set. I then asked them show me where the moon will be at midnight and just before the sun rises again. Then, like in the questions
about the sun, I asked the students to show me how the moon moves through the sky (or if they did not show it moving, I asked if the moon appears to move).

**Path of the moon**

Just as with the sun, the students demonstrated a wide range of ideas about the apparent motion of the moon. Most of the first grade students (55%) described the moon’s motion as rising straight up to the zenith, remaining there throughout the night, and then setting at the end of the night. Aletta’s answer is a typical response for this group. She pointed to the zenith for the location of the moon at the beginning of the night. She indicated that at midnight that the moon will be in the same place, “Up with the stars.” When it is almost time for morning, she indicated the sun will be down near the horizon:

Aletta: And they’re trading. The sun’s going to trade with the moon.
I: Where will the moon be when we see the sun again?
Aletta: Right down in the other place.
I: Show me again what the moon does for the entire night.
She shows the moon rising up to the zenith.
Aletta: It stays up there and when the morning comes the sun goes up there.
I: And what does the moon do?
Aletta: The moon goes to another world for them to sleep.

One additional student demonstrated a similar path. Jackson believed that the moon spent the entire night up at the zenith and set at the end of the night. He did not explain how the moon got to the zenith.
<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Grade level</th>
<th>First</th>
<th>Third</th>
<th>Eighth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the path of the moon accurate? (Mpath)</td>
<td>1. Smooth path, not through the zenith</td>
<td></td>
<td>0</td>
<td>1 (5%)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2. Smooth path, through the zenith</td>
<td></td>
<td>1 (5%)</td>
<td>11 (55%)</td>
<td>12 (55%)</td>
</tr>
<tr>
<td></td>
<td>3. More than one path (one of which is partially accurate or accurate)</td>
<td></td>
<td>1 (5%)</td>
<td>2 (10%)</td>
<td>1 (5%)</td>
</tr>
<tr>
<td></td>
<td>4. Other path, includes rising and/or setting</td>
<td></td>
<td>3 (15%)</td>
<td>0</td>
<td>1 (5%)</td>
</tr>
<tr>
<td></td>
<td>5. Moon moves up and down on one side of the sky</td>
<td></td>
<td>1 (5%)</td>
<td>4 (20%)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>6. Moon moves around the sky but does not rise and set</td>
<td></td>
<td>1 (5%)</td>
<td>2 (10%)</td>
<td>5 (25%)</td>
</tr>
<tr>
<td></td>
<td>7. Moon does not move in the sky</td>
<td></td>
<td>0</td>
<td>0</td>
<td>2 (10%)</td>
</tr>
<tr>
<td></td>
<td>8. Moon spends most of the night up at the zenith</td>
<td></td>
<td>11 (55%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>9. Unable to demonstrate path</td>
<td></td>
<td>2 (10%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Does the student show the same path for the moon as for the sun? (Msun)</td>
<td>1. Demonstrates similar path</td>
<td></td>
<td>11 (55%)</td>
<td>10 (50%)</td>
<td>10 (50%)</td>
</tr>
<tr>
<td></td>
<td>2. Demonstrates similar path, with skewed direction</td>
<td></td>
<td>0</td>
<td>4 (20%)</td>
<td>2 (10%)</td>
</tr>
<tr>
<td></td>
<td>3. Includes some similar features</td>
<td></td>
<td>1 (5%)</td>
<td>1 (5%)</td>
<td>1 (5%)</td>
</tr>
<tr>
<td></td>
<td>4. Shows more than one path</td>
<td></td>
<td>0</td>
<td>1 (5%)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>5. Not similar to the path of the sun</td>
<td></td>
<td>8 (40%)</td>
<td>4 (20%)</td>
<td>7 (35%)</td>
</tr>
<tr>
<td>Is the moon’s motion continuous? (Mcon)</td>
<td>1. Moon’s motion is continuous</td>
<td></td>
<td>6 (30%)</td>
<td>17 (85%)</td>
<td>18 (90%)</td>
</tr>
<tr>
<td></td>
<td>2. Moon stays in one place for extended periods of time</td>
<td></td>
<td>12 (60%)</td>
<td>3 (15%)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>3. Moon does not move in the sky</td>
<td></td>
<td>0</td>
<td>0</td>
<td>2 (10%)</td>
</tr>
<tr>
<td></td>
<td>4. Answer is unclear or inconsistent</td>
<td></td>
<td>2 (10%)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Only one of the first grade students demonstrated that the moon moves smoothly across the sky, through the zenith. The rest of the students described the moon’s apparent motion very differently than the actual motion of the moon, including moving around the top of the sky in multiple directions, moving but never setting, and two that did not demonstrate the moon’s apparent motion. However, both students who were unable to demonstrate the moon’s motion did indicate that they believe the moon moves.

The most common response from the third grade students was to describe the moon’s apparent motion as a smooth curve across the sky, either through zenith (55%) or just below it (5%). The next most common description, given by 20% of the third grade students, was to indicate that the moon rises and sets in the same place on the horizon. Two more students (10%) both described the moon as rising and setting in the same position on the horizon and as moving across the sky through the zenith. The other two third grade students, Chrystal and Misty, said that the moon never rises or sets. Chrystal indicated that the moon moves around the sky during the night and then moves up towards the zenith when the sun comes up: “Kinda like rising up but gets harder to see.” Misty described the moon as moving across the sky, through the zenith, during the night but then moving back around the side of the sky during the day to where it started the previous night.

Almost all of the eighth grade students either described the moon’s motion as a smooth path across the sky through the zenith (55%) or indicated that the moon never rises and sets (35%). Of the remaining two students, one student described the moon’s apparent motion as rising and setting on opposite sides of the sky but she also included sharp turns in the path she demonstrated. And one student described two different paths
for the moon in her interview. The students who indicated that the moon is always in the sky included: two students who showed the moon circling around the sky, two students who said the moon only moves a little, one student who showed the moon moving back and forth, and two students who indicated that the moon never moves.

Rick was one of the students who demonstrated the moon circling around the sky:

I: What's going to happen to the moon from say, sunset until midnight?
Rick: It like, ah, the moon like rotates around the earth so I don't know… that's a tough one."
I: So if you thought about like through the entire night, what might the moon do?
Rick: It moves, like in a circle, maybe? (He shows the moon making a circle, counter-clockwise, around the sky.)
I: So does it come back to the same spot by the end of the night?
Rick: No, probably about half way. It takes about 24 hours. Some <*> takes about a day to go around and get back to the same spot.
I: So when the sun comes up again in the morning, what happens to the moon?
Rick: The moon, (3 second pause) I don't know. This the moon right? (indicates flashlight).
I: Yeah, right.
Rick: I would think it goes around the earth and...
I: Can we still see the moon when the sun comes up again in the morning?
S: Yeah, sometimes.
I: So it's still in the sky?
S: Yeah.
I: So is the moon always in the sky?
S: Yeah

In describing the moon’s motion, Rick suggested that the moon rotates around the earth. Presumably he means that the moon orbits around the earth. Robert, who described the moon’s motion as back and forth across the sky, made a similar statement:

I: So show me again how the moon moves through the sky?
I: And so we'd see it here?
Robert: Yeah, and it just kinda as we, as it rotates around the earth it's just gonna, we can see it in different directions.

Neither of these students have an accurate understanding of how the orbit of the moon affects its apparent motion nor do they appear to know the actual period of the moon’s
orbit. Jason, one of the students who said that the moon does not move, used the earth’s motion to explain this concept:

I: Is the moon's position in the sky going to change during the night?
Jason: I don't think so. I think it's just that we rotate, the earth rotates. The moon kind of stays there.

There was an additional student who also indicated that the moon always stays in the sky. Kerrie began her interview by describing the moon’s motion as rising and setting but then switched her answer to say the moon remains in the sky. Therefore she was coded as demonstrating two different paths. After Kerrie demonstrated that the moon makes a smooth curve across the sky, I asked her what would happen to the moon when the sun comes up she realized that she had could not account for some conflicting ideas about the moon and the earth’s motions. These students’ attempts to describe the moon’s apparent motion suggest that they have not accurately integrated the ideas of the moon’s orbit or the earth’s rotation into their understanding of the moon’s apparent motion.

Students in first, third and eighth grade did not use the same description of the apparent path of the moon. Most first grade students described the moon as remaining at the zenith throughout the night and then setting when it was time for the sun to rise. The most common description from both third and eighth grade students was that the moon’s path is a smooth curve across the sky through the zenith. However, there were also more of the older students who said that the moon never sets, compared to the younger students. Forty percent of the eighth grade students said that the moon is always in the sky compared to only 10% of the third and 5% of the first grade students held this view.
Comparing the sun and moon’s paths

The actual path of the sun and moon are quite similar because they are both caused by the rotation of the earth on a day-to-day basis. Any differences in rise and set positions and altitude are dependent on the tilt of the earth with respect to its orbit and the tilt of the moon’s orbit with respect to the earth’s orbit. The full extent of these differences is of course beyond what we might reasonably expect of elementary and middle school students. However knowing whether or not the students think that the moon and sun move along similar paths is important for assessing the nature of their understanding of celestial motion.

Across the three grade levels there was no significant difference in the number of students who showed the same path for the sun and moon, $\chi^2 (1, N = 60) = 0.133, p > 0.05$. Fifty-five percent of the first grade students showed the same path for the sun and moon while 70% of the third grade students and 60% of the eighth graders showed the same path, including a few students who demonstrated that the sun and moon move across the sky in different directions. This does not mean that the students in all grades were showing the same paths for the sun and moon. As has been discussed in previous sections, there is a significant difference in the most common path of the moon shown by the first grade students compared to third and eighth grade students. Even though there was a significant difference in the most commonly expressed type of path for the moon and the sun between grade levels, within grade levels the students showed the same level of consistency in describing the path of the sun and the moon.
**Uniformity of the motion of the moon**

Most of the first grade students did not describe the moon’s apparent motion as continuous (60%). These were the students that described the moon as rising to the zenith, remaining there throughout the night, and then setting at the end of the night. Only 30% of the first grade students described the moon’s motion as moving continuously and another 10% could not be classified either way. The majority of the third grade students indicated that the moon moves continuously (85%) with the remaining 15% of the students indicating that the moon does not move at times. The eighth grade students primarily described the moon’s motion as continuous (90%) with only two students suggesting that the moon never appears to move in the sky, a concept not seen in any of the younger students, which suggests that this may be an alternative idea that developed after early elementary school.

**Summary: The apparent path of the moon**

Over half of the first grade students described a path for the moon that was consistent with rising straight up, staying at the top of the sky, then setting straight down. This concept was not described by any of the third or eighth grade students. The rest of the first grade students gave a range of possible descriptions of the moon’s apparent motion. Most of the third and eighth grade students gave the partially accurate description of the moon’s apparent motion – a smooth curve across the sky through the zenith with no indication that the moon stops moving during its path across the sky. The rest of the third grade students described a range of possible paths for the moon, most of which included rising and setting. However, most of the eighth grade students who did
not give a partially accurate description said that the moon never rises or sets but rather it remains in the sky at all times.

The other difference observed across the grade levels was that the first grade students were more likely to indicate that the moon does not move continuously across the sky. This concept was tied directly to the first grade students’ most common description of the moon’s apparent motion. All but a few of the older children indicated that the moon’s apparent motion is continuous.

Despite these differences between the students at each grade level, there was no significant difference in the percentage of students who believe that the sun and moon have a similar apparent motion. Sixty to seventy percent of the students at each grade level showed the sun and moon having the same path, though these paths were not the same across grade levels.

**Theme 7: The apparent motion of the stars**

In general, the stars appear to rise and set in the same direction and along a similar path as the sun and moon due to the earth’s rotation (though in the northern hemisphere, a fraction of the stars appear to rotate about the North Star, never rising or setting). Students were asked a series of questions to uncover their ideas about the apparent motion of the stars at night and the consequences of that motion, such as the fact that the rising and setting of stars allows us to see different stars throughout the night and that there are stars in the sky during the daytime even though we cannot see them. This is a subject that students will have far less experience with compared to either the moon or the sun for two reasons: the stars are only visible at night when most of the children are asleep and the vast number of stars in the sky make it unlikely the students would be able
to tell that a specific star has changed position over time. The distribution of students’ ideas concerning the apparent motion of the stars is shown in Table 4.7.

**Apparent motion of the stars in the sky**

The students were asked to imagine that the dome was the night sky full of stars. They were asked, “Do the stars stay in the same place in the sky throughout the night?” They were then told to imagine that the flashlight was a bright star in the sky that they see just after sunset and asked, “Where will that star be at midnight?” These questions were used to determine whether or not the students believed that the stars change position over the course of the night, if they are stationary, or if they had some other view of the apparent motion of stars. The students were not asked specifically to explain why the stars do or do not seem to move. However, some students chose to include an explanation in their description.
<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Grade level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>First</td>
</tr>
<tr>
<td>Do the stars appear to move at night?</td>
<td>1. Stars move in a smooth path</td>
<td>1 (5%)</td>
</tr>
<tr>
<td></td>
<td>2. Knows that stars appear to move, does not demonstrate accurately</td>
<td>6 (30%)</td>
</tr>
<tr>
<td></td>
<td>3. Conflicting answers: indicates stars do and do not move</td>
<td>2 (10%)</td>
</tr>
<tr>
<td></td>
<td>4. Stars do not move</td>
<td>5 (25%)</td>
</tr>
<tr>
<td></td>
<td>5. Stars only move at the end of night</td>
<td>6 (30%)</td>
</tr>
<tr>
<td>Do we see different stars during the night?</td>
<td>1. Different stars and explains using rise/set of stars or rotation of earth</td>
<td>2 (10%)</td>
</tr>
<tr>
<td></td>
<td>2. Different stars – no explanation</td>
<td>2 (10%)</td>
</tr>
<tr>
<td></td>
<td>3. Different stars across different seasons/different places on earth</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>4. Different stars but non-normative explanation</td>
<td>2 (10%)</td>
</tr>
<tr>
<td></td>
<td>5. Same stars all night long</td>
<td>13 (65%)</td>
</tr>
<tr>
<td></td>
<td>6. Unsure/confused</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>Where are the stars during the daytime?</td>
<td>1. Stars are still in the sky</td>
<td>1 (5%)</td>
</tr>
<tr>
<td></td>
<td>2. Stars are still in sky, but gives non-normative reason for why we can’t see them</td>
<td>1 (5%)</td>
</tr>
<tr>
<td></td>
<td>3. Earth turns around so we can’t see stars</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>4. Stars all go down/to other side of world</td>
<td>6 (30%)</td>
</tr>
<tr>
<td></td>
<td>5. Stars go to where the moon is</td>
<td>7 (35%)</td>
</tr>
<tr>
<td></td>
<td>6. Stars disappear</td>
<td>4 (20%)</td>
</tr>
<tr>
<td></td>
<td>7. Student doesn’t know <em>(didn’t ask)</em></td>
<td>1 (5%)</td>
</tr>
</tbody>
</table>
The eighth grade students were split between those who could give a general description of the stars moving slowly across the sky during the night (40%) and those who did not think that the stars ever seem to move (40%). There were also two students who said that the stars only move at the end of the night and two students who gave a non-normative description of the star’s apparent motion. Six of the students mentioned the rotation or spinning of the earth in their explanation of why the stars seem to move, including the two student who said that the stars only move at the end of the night.

Marina uses the earth’s rotation in her description of why she thinks the stars only move at the end of the night:

I: Do the stars stay in the same place throughout the night?
Marina: Yes?
I: OK, so if we saw a star… Let's say that's a really bright star (the flashlight), and ah, if we went outside and we saw that just after sunset, we see that star there. Around midnight, where would that star be?
Marina: Same spot?
I: And, if we go outside just before sunrise, still dark and we can still see the stars, would we see the same stars that we saw just after sunset?
Marina: Hmm, maybe not because like the s-, the earth rotates so you get different stars.
I: So we might see other stars then. Would we see any of the same stars?
Marina: We might. Maybe a couple. Maybe the brightest ones. Not like the ones that pretty much disappear.
I: And would those ones be in the same place or a different place?
Marina: They might move a little. Not like too much though.

None of the students who said that the stars do not seem to move mentioned the earth’s rotation.

The third grade students were also closely split between students who think the stars move during the night (30% were able to demonstrate this motion and 20% were not able to demonstrate this motion accurately) and the students who do not think the stars
move at all (40%). The remaining students believe the stars only move at the end of the
night (10%).

The six of the third-grade students who indicated that the stars appear to move at
night, as well as the two students who indicated that the stars only move at the end of the
night, did not use the rotation of the earth as frequently in their descriptions. Three of the
third grade students did not mention anything that could be considered an explanation.
The remaining five used other alternative ideas in their explanations: three of the students
mentioned the stars needing to be with the moon and the other two described the stars as
“floating,” such as Misty who said “They move because they are big balls of gas floating
in outer space.” Only Stewart indicated that the stars appear to move because of the
earth’s rotation. In contrast, half of the eighth grade students who indicated that the stars
seem to move used the rotation of the earth in their description.

Just as with the third and eighth grade students there was a close split between the
fraction of first grade students who believe that the stars never appear to move as with
those who think the stars do appear to move throughout the night. However, only one of
the first grade students described a smooth path for the stars (Merideth demonstrated that
a star may move up during the night and then set back down after midnight). Six of the
students (30%) did say that the stars seem to move during the night but their answers did
not include demonstrating a smooth path or included other inaccuracies such as showing
the stars moving about in multiple directions. There were also six students (30%) who
believe that the stars only move at the end of the night, when they set below the horizon
or go to the other side of the earth.
The distribution and frequency of ideas about the apparent motion of the stars was very similar across each of the grade levels, though the third and eighth grade students were much more similar to each other than to the youngest students. Approximately the same percentage of students at each grade level indicated that the stars never appear to move. The third and eighth grade students who believe that the stars appear to move were more accurate in their descriptions than the first grade students. More of the first grade students believed that the stars only move at the end of the night compared to the older students. Finally, a larger percentage of the eighth grade students used the earth’s rotation in their descriptions than did the younger students.

**Different stars during the night**

After asking the students whether or not the stars seem to move in the sky during the night, they were asked whether or not we see the same stars just before sunrise as we see just after sunset. This was asked to see if they knew that the patterns of stars we see changes over the course of the night. The distribution of ideas on this topic did not change significantly from first through eighth grade. Over half of the students in first, third, and eighth grade do not think that we see different stars in the sky during the night (65%, 60%, and 65%, respectively). Only a few students gave an accurate description of seeing different stars throughout the night by either explaining that the earth rotates or that the stars appear to rise and set. Two students in first grade and one each in third and eighth grade used the concept of rising and setting in their description of why we see different stars throughout the night. Two of the eighth grade students and one third grade student used the rotation of the earth to explain why we see different stars during the night. A few more students at each grade level indicated we see different stars through
out the night but without explanation (15% in first, 10% in third) or a non-normative explanation (10% in first, 25% in third, and 5% in eighth).

Three of the eighth grade students both did not think we can see different stars during the night but knew that we see different stars across the seasons. Kelly initially described the stars’ motion in the night as a circle. I later asked her about the change in the stars over the entire night:

I: And so, the stars that we saw just after sunset, do we see those same stars just before sunrise?
Kelly: Yeah. Because different - It's actually <***> because it doesn't move that way because they don't go on the other side of the world. It's just...
I: So show me the motion again.
Kelly: It would go like that.
She shows the star making a counterclockwise circle around the sky.
I: What will happen after that?
Kelly: It will go kinda around. Because if you look at one of those star finders things during the seasons you see the different parts of the sky.
I: So how long does that motion take?
Kelly: To go all the way around.
I: Yeah.
Kelly: It might be a year? Because if each season different quarter of the way <*> to go all the way around.

Kelly mentioned the use of a “star finder,” an instrument used to find the constellations in the night sky that can be set for any time of night on any night of the year.

**The stars during the daytime**

An accurate description of what happens to the stars during the daytime would include the fact that there are still stars in the sky but that the sun makes the sky too bright for us to see them. Only two of the first grade students indicated that the stars would still be in the sky. Sunny was coded as accurate: “Because they glow, they glow. And when the sun’s up they still glow but you can’t see them because the sun’s so bright.” Cecelia gave a non-normative explanation, suggesting that the stars “go into the
clouds” during the day. The most common explanation for the stars’ disappearance during the day was that they either go down (30%) or go to the same location as the moon (35%). These two concepts are similar because many of the first grade students indicated that the moon goes down during the daytime, such as in Barbie’s response: “They go down where the moon goes. They follow the moon. It’s like follow the leader.” There were also four students (20%) that indicated that the stars would not be in the sky during the day but gave other non-normative explanations (ex. Merideth: “They go into the sun.”) or no explanation.

Nearly half of the third grade students gave an accurate response to this question (45%) with an additional student saying that the stars are still in the sky but are not visible because of the clouds. The rest either indicated that the stars all go down at the end of the night (10%) or that they go with the moon (25%). Another three students (15%) could not explain what happens to the stars during the day.

In the eighth grade group, 75% of the students were able to accurately state that the stars are still in the sky and are not visible because the sun or the sky is too bright. Brenda’s response is typical of most of the eighth grade students coded as accurate:

I: And then, what's going to happen [to the stars] when the sun comes up? Brenda: You won't be able to see them anymore. I: Will the stars still be up there in the sky? Brenda: Yeah. I: How come we can't see them? Brenda: Because the sun... it's brighter out so like you can not, you can't really see the white from the stars. It's more brighter out so you can't see them.

Two more students (10%) gave non-normative explanations for why we cannot see the stars even though they are still in the sky. Thomas suggested that we cannot see the stars “Because reflection of the sun maybe? And they have their own little light so, I don't
know. They just probably go out.” Nancy said that we cannot see the stars because “They are too far away.” There were also two students who indicated that the earth turns to face away from the stars during the daytime.

The major difference between the grades in this topic is the increase in the percentage of students who can give an accurate explanation to the disappearance of the stars during the daytime in the older students compared to the younger. Only one of the first grade students gave an accurate response compared to nearly half of the third grade students and three-quarters of the eighth grade students. This is inversely related to the number of students at each level who believe that all of the stars go down (including the “with the moon” concept) or are on the other side of the earth during the daytime.

**Summary: The apparent motion of the stars**

The students interviewed had very little understanding of the apparent motion of the stars during the night. This could be anticipated because most students have very little experience with studying or observing the stars at night. Thus, despite being significantly older, even the eighth grade students demonstrated very little knowledge of the apparent motion of the stars or the fact that we see different stars throughout the night. However, the eighth grade students did begin using the earth’s rotation in their answers to explain the motion they referred to, a trend not seen in the younger grades.

While more students in third and eighth grade were able to describe the apparent motion of the stars than in first grade, the fraction of students who believe the stars never appear to move was essentially constant across the grade levels interviewed. Similarly, most students in each grade level interviewed did not know that we see different stars over the course of the night because the stars rise and set.
There was an improvement in third and eighth grade in the fraction of students who could accurately explain why we do not see any stars in the daytime sky. The first grade students were more likely to describe the stars as all going down or with the moon than to indicate that there are still stars in the sky. The third grade students were nearly split between those who think there are still stars in the sky during the day and those that believe they have all gone down. The majority of the eighth grade students gave an accurate description of why the stars disappear during the daytime.

**Theme 8: Day and night**

Table 4.8 shows the distribution of students’ responses to the last questions of the interview: “Where is the sun at night?” and “What is going to happen to make it daytime again?”

**The sun’s location at night**

Most first grade students (55%) described the sun as “down” at night. The rest of the students gave a variety of ideas including:

- Daphne: “On the other part of the world.”
- Aletta: “Shining at the other world where the moon was.”
- Bobby: “Where the stars are.”
- Ralph: “The sun will be where it goes when it’s dark out.”
- Cecelia: “Behind the clouds. Far away.”
- Toby: “Probably behind the moon.”

There was also one student who did not know and one who gave an answer that was unclear.
### Table 4.8 Day and Night

<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Grade level</th>
<th>First</th>
<th>Third</th>
<th>Eighth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where is the sun at night?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. On the other side of the earth</td>
<td>0</td>
<td></td>
<td>11 (55%)</td>
<td>16 (80%)</td>
<td></td>
</tr>
<tr>
<td>2. At another place on the world</td>
<td>2 (10%)</td>
<td></td>
<td>2 (10%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3. Below the horizon/ground</td>
<td>11 (55%)</td>
<td></td>
<td>1 (5%)</td>
<td>2 (10%)</td>
<td></td>
</tr>
<tr>
<td>4. Behind the moon or giving light to the moon.</td>
<td>1 (5%)</td>
<td></td>
<td>1 (5%)</td>
<td>1 (5%)</td>
<td></td>
</tr>
<tr>
<td>5. Behind the clouds</td>
<td>1 (5%)</td>
<td></td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6. Goes to where it is dark or another night</td>
<td>2 (10%)</td>
<td></td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>7. Becomes a star</td>
<td>0</td>
<td></td>
<td>1 (5%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8. Does not know/Answer is unclear</td>
<td>3 (15%)(^a)</td>
<td></td>
<td>4 (20%)</td>
<td>1 (5%)</td>
<td></td>
</tr>
<tr>
<td>What happens to make it daytime?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. The earth turns around to face the sun</td>
<td>0</td>
<td></td>
<td>3 (15%)</td>
<td>14 (70%)</td>
<td></td>
</tr>
<tr>
<td>2. The sun rises</td>
<td>13 (65%)</td>
<td></td>
<td>4 (20%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3. Sun is in the sky (does not explain)</td>
<td>1 (5%)</td>
<td></td>
<td>2 (10%)</td>
<td>2 (10%)</td>
<td></td>
</tr>
<tr>
<td>4. Sun revolves around earth</td>
<td>0</td>
<td></td>
<td>5 (25%)(^c)</td>
<td>2 (10%)</td>
<td></td>
</tr>
<tr>
<td>5. Earth revolves around sun</td>
<td>0</td>
<td></td>
<td>1 (5%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6. Sun and moon switch spots</td>
<td>1 (5%)</td>
<td></td>
<td>5 (25%)</td>
<td>1 (5%)</td>
<td></td>
</tr>
<tr>
<td>7. Sun comes down from space</td>
<td>0</td>
<td></td>
<td>1 (5%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8. Unknown or answer unclear</td>
<td>5 (25%)(^b)</td>
<td></td>
<td>0</td>
<td>1 (5%)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Did not ask one student.
\(^b\) Did not ask two students.
\(^c\) One student who indicated that the sun moves to make it daytime also indicated that the earth rotates in another part of her answer.

Half of the third grade students (50%) indicated that the sun is on the other side of the earth at night. Two more students (10%) indicated that the sun was at another location on the earth (Jack: “The sun is in China.”; Audrey: “The sun at night as moved
to like Texas or something.”). Like the younger students, the third grade students also had a range of non-normative ideas:

- Misty: “It’s down and it’s not glowing anymore because it’s reflecting off and giving it to the moon.”
- Charles: “Behind the moon, making it glow.”
- Chyrstal: “I think it either like moved away or it went all the way around to the other side.”
- Diane: “It’s one of the stars.”

There were an additional four students (20%) who said they did not know where the sun is at night.

The majority of the eighth grade students (80%) were coded as accurate. Many of these students simply said "On the other side of the earth." There were also two students (10%) who indicated that the sun goes below the horizon. Rick was the only eighth grade student to give a highly non-normative response to this question. His response indicates that he thinks the sun is still up in the sky during the night:

Rick: It's still up there, but I think it's, the light, the light that ah, the sun gives off, it goes like, makes the moon…
I: So all that light is going into the moon…
Rick: Making, makes it that <*> show, and like say, it might show a side and not show the other half. Like I was saying it might have a curve sometimes. So it might just show on that one side and that might be a shade, or a shadow.
I: But the sun is still up in the sky?
Rick: Yeah.
I: And what's going to happen to make it daytime again?
Rick: The moon's going to go around the sun, and be behind it.
I: And then we'll be able to see the sun again?
Rick: Yeah.

There was also one eighth grade student who did not know where the sun is at night.

Between first and third grade there is a shift in the most commonly given answer to the sun’s nighttime location. Half of the first grade students indicated that the sun is “down” at night, without saying that it is on the other side of the world. Similarly, half of
the third grade students said that the sun is on the other side of the world but only one said it was below the horizon. This shift suggests that the first grade students had not been exposed to instruction on the day-night cycle while the third grade students had learned some of these concepts in school (especially given the uniformity of the descriptions provided by those students). However, approximately half of both the first and third grade students gave a variety of non-normative responses or did not know where the sun is at night. Overall, the eighth grade students had a more accurate understanding of this concept than most of the younger students. They primarily answered that the sun is on the other side of the earth, with only a few indicating that it is below the horizon or a non-normative response.

**What happens to make it day?**

The majority of first grade students (65%) replied that the sun rises to make it daytime. Aletta’s response is typical of these students: “The sun starts coming up. The sun rises.” Bobby did not explain how the sun got in the sky; he only said “It like fire” but agreed when I asked him if the sun moves. Toby’s answer implied that he thinks the sun and moon switch: “Sun would go in front of the moon.” Three more students (15%) gave answers that were unclear.

The third grade students gave a wide range of answers. The two most common answers, each given by 25% of the students, were a) to implicate a switch between the moon and the sun or b) indicate that the sun moves around the earth. Charles said that the “sun comes out from behind the moon.” Justine said that the “moon might maybe turn into the sun.” The rest of the third grade students gave answers that included: the
earth turns around to face the sun, the sun rises, the sun comes down from space, and the
earth revolves around the sun.

The majority of eighth grade students (70%) gave the accurate response that the
earth turns around to face the sun again. One student said that the sun rises. The rest of
the eighth grade students either did not explain how the sun gets into the sky (10%),
indicated that the sun will revolve around to our side of the earth (10%), or describe the
sun and moon switching places (5%).

There is a split in the descriptions when we compare the first and the eighth grade
students. Most of first grade students (65%) said that the sun will rise and most of the
eighth grade students (70%) said that the earth will turn around to face the sun. However,
the third grade students gave a wide range of descriptions for this phenomenon. There is
no clear “preferred” answer among the students in this grade.

**Summary: Day and night**

Many of the first grade students give a simple explanation based on observations
of the world for day and night; the sun goes down at night and rises up during the day.
The third and eighth grade students were more likely to explain that the sun is on the
other side of the world than simply down, at night. However, unlike the eighth grade
students who explained daytime as the earth turning to face the sun or the first grade
students who explained by saying the sun rises, the third grade students gave a broad
range of explanations. A few of these explanations involved the earth moving but many
involved the sun moving or incorporated the moon into the concept.
Theme 9: Comparisons of the disappearance of the sun and moon

This section describes the results of comparing students’ explanations for the disappearance of the sun and moon from the sky. The questions used to assess the nature of the students’ ideas in this area were:

- Where is the moon when we can’t see it in the sky?
- Where is the sun at night when we can’t see it?

These topics were discussed separately above. Additional information from other areas of the interview was used when these answers did not provide enough information. Some students were categorized as “unclear” when their answers were unclear or if they said “I don’t know” for either or both of the questions. The codes are not accurate or non-normative because only considered whether or not they used the same description not the same accurate description. Table 4.9 gives the distribution of answer by grade level.

Table 4.9 Comparisons of the disappearance of the sun and moon

<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Grade level</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the student use the same explanation for why we can’t see the sun at night and why we cannot always see the moon? (SuMo)</td>
<td>1. Uses same explanation or description</td>
<td>First</td>
<td>Third</td>
<td>Eighth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16 (80%)</td>
<td>9 (45%)</td>
<td>12 (60%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Uses a different explanation or description</td>
<td>1 (5%)</td>
<td>7 (35%)</td>
<td>7 (35%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Answers are unclear or unknown</td>
<td>3 (15%)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4 (20%)</td>
<td>1 (5%)</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> One student was not asked about the sun.

The majority of first grade students (80%) used the same description for the sun and moon’s disappearance. Neil is typical of many of the first grade students who described both the sun and moon as being “down” when we cannot see them:


**Moon:**
I: Where will the moon be when we see the sun again?
Neil: Down. (He points down.)
I: Where does the moon go when we can’t see it?
Neil: Usually see <*> it goes behind the hills. I don’t really, really know where it goes after that but…

**Sun:**
I: Where is the sun when we can’t see it?
Neil: Down behind something.

While not an accurate description of what actually causes the sun to disappear at night and the moon to disappear from the sky for half of the day, he does use the same description for both celestial objects.

Less than half of the third grade students (45%) used the same explanation. Seven of these students said that both the sun and moon are on the other side of the earth. One of the other students said that the sun and moon go to another state and the indicated that the sun moves behind the moon and vice versa. Nearly the same percentage of students (35%) used different explanations and some (20%) could not be classified because their answers were unclear or they did not know what happened to one of the objects. Slightly more of the eighth grade students (60%) gave the same explanation compared to the third grade students. All but one explained that both the sun and the moon are on the other side of the earth when they are not visible. Some of these students said "On the other side of the earth," as was the common response from the third grade students who gave the same explanations. Other eighth grade students used the earth’s rotation, such as Clara’s response to the disappearance of the moon: “Uhm, maybe the earth's rotated enough that we can't see it I guess.” The third grade students did not use the earth’s rotation in their answers. Rick, the other eighth grade student who used the same description, said that both the sun and the moon are always in the sky.
Moon:
I: So is the moon always in the sky?
Rick: Yeah
I: Are there times when we can't see the moon?
Rick: Yeah, like when the sun's real bright you can't really see it sometimes.
I: But it would still be...
Rick: Yeah, still up there.

Sun:
I: Where is the sun at night?
Rick: It's still up there, but I think it's, the light, the light that ah, the sun gives off, it goes like, makes the moon…
I: So all that light is going into the moon…
Rick: Making, makes it that <*> show, and like say, it might show a side and not show the other half. Like I was saying it might have a curve sometimes. So it might just show on that one side and that might be a shade, or a shadow.
I: But the sun is still up in the sky?
Rick: Yeah.

Four of the students in third grade who gave different explanations said that the sun is on the other side of the earth at night but used a different explanation for the moon.

All of the eighth grade students who gave different explanations for the disappearance of the sun and the moon used the rotation of the earth to explain the disappearance of the sun but not the disappearance of the moon from the sky. The most common idea expressed for the disappearance of the moon among students who used a different explanation for the sun was that the moon is always in the sky. Four of the third grade students and six of eighth grade students fit this pattern, such as in Gail’s description:

Moon:
I: Does the moon move through the sky during the night?
Gail: A little.
I: So then, what happens to the moon when the sun comes up?
Gail: It's still there. It's just harder to see it.
I: What about when we can't see the moon?
Gail: The sun's light's not reflecting on it.
I: So, is the moon always up there in the sky?
She agrees yes.
Sun:
I: Where is the sun when we can’t see it at night?
Gail: On the other half of the world.
I: What’s going to happen to make it daytime again?
Gail: The world's going to rotate so we're back on the side of the sun.

Gail used rotation to explain the day and night cycle but did not include the motion of the moon as a consequence of this rotation.

A larger percentage of first grade students used the same explanation for the disappearance of the sun and moon, compared to both the third and eighth grade students interviewed. There is a significant difference between the first and third grade students ($\chi^2 (1, N = 34) = 7.40, p<0.05$) and between the first and eighth grade students ($\chi^2 (1, N = 36) = 4.98, p<0.05$), if the students with answers that could be coded as either the same explanation or different explanation are compared. There is no significant difference between the third and eighth grade students regarding the consistency of their explanations of the disappearance of the sun and moon, $\chi^2 (1, N = 36) = 0.39, p>0.05$.

This suggests that first grade students are more likely to use the same type of explanation of where the sun is at night as where the moon is when not visible, compared to the older students.

Comparing students’ explanations for the disappearance of the sun and moon reveals another interesting difference beyond just using different mechanisms to explain the two phenomena. Several students gave explanations that appeared to contradict earlier descriptions of celestial motion. Seven eighth-grade students (35%), five third-grade students (25%), and none of the first grade students showed logical inconsistencies when I compared their answers to “What happens to the sun at night” and “Where is the moon when we cannot see it.”
Four of the third grade students demonstrate the same concept of the moon always being in the sky but the earth moving to face towards and away from the sun. Some of these students still demonstrated that the moon rises and sets. For example, Jack demonstrated the moon crossing the sky through the zenith but also just before morning he said “It’s always in the sky. Can’t really see it very well” and that it is “in the clouds” when it is not visible (his explanation for the sun’s disappearance at night is that the sun “goes all the way around the world”). The other student, Justine, said that the moon “goes down where we can’t see it” during the day and then later said that the moon turns into the sun to make it daytime.

All seven of the eighth grade students who demonstrated logical inconsistencies had the same logical consistency. Each of these students both indicated that the moon is always somewhere up in the sky and used the earth’s rotation to explain the sun’s nightly disappearance. Kerrie was particularly interesting in that, unlike the other six students, she recognized that there was a problem in her explanation. She used the rotation of the earth to explain why we do not see the sun at night and to explain its apparent motion during the day. She initially demonstrated the moon’s path as a straight line through the zenith from east to west:

I: What's going to happen [to the moon] when the sun comes up again?
Kerrie: It'll...(3 second pause). Good question. Can't really transport back over here. And then, hmm, hadn't really thought of that before. If the rotation of the earth takes 24 hours, like it's spinning right, so you can see it during the day... I don't know. I hadn't thought about that before. I know you can see it during the day and I know you can see it at night. I don't really pay attention to where it is.
I: So, if I asked you what it does over the course of the night, what would you say right now?
Kerrie: Right now, I would think it does about the same thing the sun does. It rises and it sets.
I: And then during the daytime, what does the moon do?
Kerrie: It kinda does about the same thing. But it doesn't really rise and it doesn't really set. Like it doesn't really set like the sun.
I: So, it's still up in the sky?
Kerrie: Yeah, maybe thinking about it, it doesn't really move at all. Maybe it just stays in one place. I hadn't really thought about the moon in the daytime. <*> in the daytime. Yeah, so it could like rise and set like the sun, but not exactly, like you wouldn't see it going over like the horizon ever. Maybe it would just stay in place.
I: Are there ever times when we can't see the moon?
Kerrie: When it's cloudy. And there's like a new moon. Like, just like the dark circle you can see. You can't really see the moon exactly. But you can see where it is, sometimes. Like what happens when you can just see the dark edge. Yeah.
I: Yeah, so there's times when it's dark, but it's still up there.
Kerrie: Yeah.

Summary: Explanation of the disappearance of the sun and moon

The students in first grade were significantly more likely to use the same description when asked to explain what happens to the sun at night and why the moon is not always visible in the sky compared to the older students. However, most of the first grade students did not use the same explanations that were used by the older students. The inconsistencies in the older students’ explanations for the sun and moon occurred primarily because these students suggested that the moon is always in the sky while the sun is on the other side of the earth at night. Students who used the rotation of the earth to explain the sun’s apparent motion but not the moon’s apparent motion revealed inconsistencies in how they view celestial motion.

Discussion: Children’s Understanding of Celestial Motion

Apparent motion of the sun, moon and stars

In first grade, most students’ beliefs about the apparent motion of the sun, moon and stars are very different from the accurate description of these motions. One trend
observed across the first grade students was that many believe that the sun and moon rise up to the zenith, remaining there without moving, and then set, rather than moving continuously across the sky. This is similar to some of the students’ belief that the stars are up in the sky, unmoving, throughout the night but then move down below the ground or to where the moon is at the end of the night (though more first grade students believe that the stars never move, or are unable to describe their motion). The first grade students also gave a wide-ranging set of descriptions of the sun’s apparent motion (with over a third describing a path for the sun that did not resemble the rising and setting motion of the sun and was unique to that student).

As a whole, the first grade students have not developed the understanding that all celestial objects appear to rise and set, in the same direction, along similar paths. The apparent celestial motion of the sun, moon and stars demonstrated by most first grade students is not surprising considering that students at this age have had limited opportunities to observe the changing location of celestial objects or to learn about their motions in schools and other settings. Their descriptions match simple observations that the sun is “up” in the sky during the day and “down” and night. Similarly they may have observed, or been told, that the moon and stars are “up” in the sky at night. Without experiences to demonstrate that the position of these objects change slowly over time, the interpretation that they move up to the top of the sky, remain there, and then move back down would fit their basic knowledge of these objects.

By third grade, most of the students have a more accurate view of the apparent motion of the sun and moon (and to a lesser extent, the stars). The students primarily use one of two ways of describing the apparent motion of the sun. The majority of third
grade students believe that the sun has a smooth path across the sky through the zenith. The next most commonly held belief is that the sun rises and sets in the same place in the sky (a belief also held by a large percentage of the first grade students). Unlike many of the younger students, the paths most commonly demonstrated by third grade students showed the sun moving continuously throughout the day. The only major difference in these paths is that some students have not yet figured out that the sun rises and sets on opposite sides of the sky. This may be due to a lack of experience in observing the location of where the sun rose or set or because children are still developing their spatial orientation abilities (Roberts & Aman, 1993). The shift in how students describe the sun’s motion from first to third grade is also seen in their description of the moon’s apparent motion. Most first grade students think the moon spends most of the night up at the zenith while none of the third graders held this belief. Slightly more than half now hold the partially accurate view that the moon rises and sets, in a smooth path through the zenith, on opposite sides of the sky (though a handful of third grade students also believe that the moon rises and sets in the same place on the horizon). Third grade students are more likely to be able to describe and demonstrate that the stars appear to move across the sky during the night, though the same large fraction of students believes that the stars never move as was seen in first grade.

Overall, the third grade students exhibited a higher level of accuracy in their answers compared to the first grade students. Most have made the shift to viewing celestial objects as moving slowly across the sky rather than staying fixed in the sky between rising and setting. However, there is still a large minority of third grade students that have some of the same non-normative views of the apparent motion of the sun, moon
and stars as the first grade students. And there is still the same large portion of students who believe the stars never appear to move. There is no improvement in the concept that we see different stars throughout the night.

The eighth grade students continue the trend towards giving partially accurate descriptions of the apparent motion of the sun, but not the moon or stars. All of the eighth grade students demonstrate that they believe the sun rises and sets on opposite sides of the sky. And almost all described this motion as a smooth path across the sky, though the alternative idea that the sun passes directly overhead was just as strong with the older students as with the younger. There is no improvement in the number of students who give a partially accurate description of the motion of the moon, though there is a shift. First, unlike the younger students, none of the eighth graders described the moon as rising and setting in the same place. By eighth grade, students have learned that the moon rises and sets on opposite sides of the sky, as does the sun. Second, while slightly more than half of the eighth grade students give a partially accurate description, a large number of the students claimed that the moon is always in the sky (either circling around the sky or staying in one place). This was seen in a smaller portion of the younger students. Similarly, there is no significant difference in the responses given by eighth grade or third grade students concerning the apparent motion of the stars or the idea that we see different stars throughout the night. The students’ belief that we see the same stars all night long reveals that the vast majority of students (at all grades interviewed) either do not believe the stars rise and set or do not conclude that the stars rising and setting results in observing different stars throughout the night.
There was little improvement in students’ understanding of the apparent motion of stars between third and eighth grade. This is not surprising if we consider that children do not have many opportunities to make the kind of direct observations that would improve their understanding of this phenomenon. The necessary observations are likely to be difficult for adults as well because few people have the time or inclination to observe a night’s worth of observations or to extend their observations over months. American culture does not encourage children to stay outside at night to look at the stars, regardless of whether they are in an urban or suburban setting.

Another way the students may learn about the apparent motion of the stars is through school instruction. Given that adults are not likely to have an accurate knowledge of apparent celestial motion it is also worth considering that children may be getting inaccurate instruction from parents and teachers. Many of the eighth grade students mentioned the earth’s rotation in their interviews making it clear that they have learned about this concept. The lack of change also suggests that students are not making the connection between the rotation of the earth and the resulting apparent motion of the stars.

Slightly more than half of students at all grade levels believe that the sun and the moon exhibit the same apparent motion. What is interesting here is that the same fraction of the students are using the same description for the sun and the moon’s apparent motion, even though at the different grade levels the students are more likely to use one apparent path over another. This suggests that as students’ understanding of the apparent motion of the sun (or moon) changes that this extends to how they explain the motion of the other celestial object. Given that students have more experience with observing and
talking about the sun’s apparent motion it is likely that the change is initially with the sun’s motion. This large percentage of students using the same description seems to support the highly coherent and organized Framework model of students understanding (Vosniadou & Brewer, 1994; Vosniadou, 2002a, 2002b).

There are two previous studies that addressed knowledge of apparent celestial motion, though not in the same level of detail as described in the present study. Sharp (1996) interviewed 42 students (ages 10 and 11 years) in England about the apparent motion of the sun, moon and stars. He found that about three-fourths of the students “demonstrated verbally or with the use of a sketch or gesture that the sun appeared at ‘sunrise, close to the ground’ in the morning, rising in the sky to its highest point at, commonly, ‘midday’, descending again ‘towards the ground at sunset’, moving from ‘one side of the sky to the other’ (p. 694).” This is consistent with the fraction of students who described a similar path in my interviews in third grade (average age of 8.7 years) and eighth grade students (average age of 13.8 years). However, Sharp found far fewer students (36%) who believe the moon has apparent motion compared to my study (100% of the third and 90% of the eighth grade students). Similarly, his study found that only 14% of the students were aware of the stars apparent motion, compared to 60% of both the third and eighth grade students in my study. This interesting difference may be due to the nature of the interview. Sharp’s study coded the children’s understanding based on verbal responses, the use of a sketch or a gesture (though the exact questions used are not reported). This suggests that simply asking the students if the moon or stars appear to move would yield a different response than beginning by asking where a specific star or the moon is located at different times of the night (the strategy used in this study).
Mant and Summers (1993) examined the understanding of apparent celestial motion of 20 elementary teachers in the UK. Their interview protocol involved the use of a 3-D model to represent a person standing on a small mountain, surrounded by a circular card that represented the horizon. The teachers described what the observer would see in the sky with respect to this model. The results for the apparent path of the sun in the sky were similar to the eighth grade students in my study. Eighty percent of the teachers described the sun’s path as moving across the sky (4 of the 20 did not demonstrate knowledge of the path of the sun) compared to all of the eighth grade students in my sample who were able to describe a similar path. The major difference was that all but one of the teachers said that the sun does not pass directly overhead compared to only 10% of the eighth grade students who indicated that the sun does not always pass directly overhead.¹⁰

Other surveys of middle and high school students are consistent with the results of my interviews with eighth grade students concerning the sun passing through the zenith. Lightman and Sadler (1993) found that only 8% of U.S. students surveyed knew that the sun never passes directly overhead. Trumpler (2001a) found that 32% of Israeli middle school students surveyed gave an accurate response to this question.

The results of Mant and Summers’ interviews about the apparent motion of the moon and stars match more closely with the eighth grade students interviewed in this study. They found that 20% of the teachers said that the moon does not move in a period of time of one day, compared to 10% of eighth grade students. However, 88% of the teachers who said that the moon appears to move were described as “path unknown”

¹⁰ This increases to 35% if we include the students who gave inaccurate demonstrations compared to their accurate verbal response.
though some of these did include rising and setting rather than a difference in knowledge. It is possible that this is due to teachers’ inability to describe or demonstrate in the constraints of that interview setting. The teachers had a similar level of knowledge of the apparent motion of the stars with 60% giving a description of the apparent motion of the stars compared to 50% of the eighth grade students in my study.

The comparison of the eighth grade students in this study with the teachers’ knowledge of apparent celestial motion suggests that while knowledge of the apparent motion of the sun may improve after middle school, basic knowledge of the apparent motion of the moon and the stars is less likely to improve. The teachers are likely to have improved because (a) they have had more opportunities to learn about the sun’s motion in formal and informal educational settings and (b) they have had more years to develop personal observations to help them understand the sun’s motion, possibly because they have an interest improving their understanding of the subject. These experiences do not appear to have extended to improved knowledge of the moon and stars.

**Seasonal change in the sun’s path**

I also examined how students’ understanding of the difference between the sun’s path in summer and winter changes from first through eighth grade. Overall, there is no improvement in students’ knowledge of this theme. Almost all of the third and eighth grade students described the sun as having the same length of path in summer and winter. Half of the first grade students described paths that were non-normative and thus not comparable in length. The rest were the same as the older students, showing the same length path in both season. The same pattern was seen at each grade level for their understanding of the changing altitude of the sun at noon. Very few students at each
grade level know that the sun is lower in winter than summer, and there is no improvement seen when comparing older to younger students. However, looking across the grade levels at the students’ knowledge of when the sun is highest in the sky shows that by eighth grade most of the students know this occurs at noon. The number of students who believe that the sun is highest at noon in the winter is lower because a handful of students believe that the time that the sun reaches its highest altitude changes between the seasons.

It is not surprising that children are unfamiliar with the change in the path length and altitude of the sun across the seasons. These are challenging topics to learn just by everyday experiences. First, the brightness of the sun means that we tend to avoid looking in its direction. Second, to determine the length of the sun’s path on a given day requires multiple observations of the sun’s location (rising, midday, and setting). This problem becomes more challenging when considering the difference between the sun’s path and altitude between seasons because the change occurs slowly over many weeks and months.

The study examining teachers’ knowledge of apparent celestial motion also included the seasonal change in the sun’s altitude (Mant & Summers, 1993). A much higher percentage of the teachers knew that the sun is higher in summer than in winter, compared to the eighth grade students in this study (85% and 15%, respectively). Again, this suggests that knowledge of the pattern of the sun’s motion may improve after middle school. The teachers, due to their age, have had many more years to observe the change in the sun’s altitude across the seasons than the eighth grade students.
Actual motion of the sun in the sky

I was curious about how the students would describe the very slow apparent motion of the sun if asked what it is doing ‘in the sky right now.’ If we glance at the sun, it does not appear to be moving. However, all of the students indicated that the sun changes position in the sky between sunset and sunrise, though not all of the youngest students described this as a continuous motion. This question examined how the students would account for the very slow apparent motion of the sun. Among the eighth grade students, the most popular answers were that the sun does not appear to be moving because 1) we are moving, or 2) it is moving very slowly. This may not be a clear indication of a difference in how the students think about the sun’s actual and apparent motion. Some students may say that the sun is moving slowly when really they mean it appears that the sun is moving very slowly. These are the most popular answers among the third grade students as well, though given by fewer students.

The first grade students were clearly different in their knowledge than the older students. The median response in first grade was that they do not know why the sun does not appear to be moving. Another six students gave answers that were highly non-normative (to the extent that some were not understandable or did not seem to answer the question). These responses suggests that even though first grade students can talk about the broad description of where the sun is at different times of day, they do not have the conceptual understanding to go any deeper. This is likely to be explained by the limited experience that first grade students have with learning about the actual motion of the sun and earth and how this relates to apparent motion. It is likely that the students had never tried to account for the sun’s apparent slow motion. It may also relate to a lack of
understanding of how an object can move so slowly that its motion is not readily detectable.

**Apparent change in the appearance of the moon**

There is a clear shift with grade in knowledge of the amount of time it takes for the appearance of the moon to change, though even in eighth grade over a quarter of the students gave a non-normative response to how long this takes. Only one of the first grade students compared to half of the third and nearly three-quarters of the eighth grade students demonstrated an accurate knowledge of this concept. The students in first grade may not have learned about the phases of the moon and how long it takes to go through a complete cycle and may have had fewer opportunities than the older children to make their own observations of changes in the moon’s appearance. However, the same number of first and third grade students said that it takes less than a night for a significant change in the appearance of the moon. Even though most of the eighth grade students were aware of the time for the moon to go through its phases, it is unlikely that most of the eighth grade students would have given the accurate explanation for what causes the changing appearance. Baxter (1989) found that in a sample of 13- and 14-year-olds the most common description of what causes the change in the phase of the moon was the inaccurate idea that the earth’s shadow is covering the moon. It is more likely that the improved knowledge comes from learning in school the length of time for a cycle of the moon’s phases to complete than the full explanation of why the phases of the moon change.
Disappearance of the sun, moon and stars

I also examined the students’ descriptions of where the sun, moon and stars are when we cannot see them in the sky. Vosniadou and Brewer’s (1994) study of elementary students’ knowledge of the day/night cycle also examined these topics with first, third, and fifth grade students. The purpose of their study was primarily to describe and compare the students’ mental models of the underlying cause of the day and night cycle via the relationship between the sun, earth, moon and stars. In contrast, my study focused on students’ beliefs about the appearance and motion of the sun, moon, and stars from our earth-based perspective, with less time spent on the students’ descriptions of the mechanisms for these motions. However, my questions about the sun, moon and stars’ disappearance as well as what happens to make it day did bring out some of the students’ views of actual as well as apparent motion. In this section, I will describe the results of the present study and compare these with Vosniadou and Brewer’s findings, when relevant.

The students in my study were asked about the location of the moon when we cannot see it to further analyze how their understanding of celestial motion extends to when the moon is not in the sky. The number of students who said that the moon is on the other side of the earth increases from only 10% in first grade, 40% in third grade, to 60% in eighth grade. However, the number of first grade students who indicated that the moon is “down” is about the same as the number of eighth graders who say it is on the other side of the world. This suggests that some of the shift across the grade levels is a shift in how they view the earth and not necessarily that they have completely replaced their understanding of the moon’s disappearance.
One of the most surprising results of this study was that the number of students who think the moon is *always* in the sky increased in the older students. The only indication of this idea among the first grade students was the two students who said that moon is behind the clouds when we cannot see it. This increases to six students (two used the cloud explanation) in third and seven in eighth grade (with no students using the cloud explanation). This shift may be the result students’ assimilating new scientific ideas learned in school with their current concepts of the appearance of the moon in the sky. Perhaps the students believe that because the moon is always out in space and the moon orbits around the earth then this means that the moon is always in the sky. Another possible explanation is how the children interpret the concept of sky. If students consider “the sky” as the entire atmosphere surrounding the earth, and they believe the moon is in the sky/atmosphere, then perhaps some believe that the moon is always in the sky even on the other side of the earth. This would be an interesting concept to explore in more depth with elementary and middle school students. It would also be interesting to explore how geographically sensitive this concept is because of the prevalence of cloud explanations among the younger students.

Vosniadou and Brewer (1994) also investigated the students’ understanding of the motion of the moon. They asked the following questions:

1. Does the moon move?
2. Does the moon move along with you when you go for a walk?
3. Does the moon move when you are asleep in your bed?
4. Why does the moon move?

Their results show a clear shift between first grade students and third and fifth grade students. The younger students described the moon as moving, with a similar description as many of the first grade students in this study (“that it moves in an up/down fashion
with respect to the earth’s surface” p. 159). The third and fifth grade students were more likely to say that moon does not move, reflecting the belief that the earth is rotating and the moon remains fixed in place. Perhaps this shift seen in how the students describe the apparent motion of the moon is a reflection of the shift in their descriptions of the moon’s actual motion.

Just as with the moon, I found a clear shift between the first and third grade in how students explain the disappearance of the sun at night. In first grade, about half of the students believe that the sun is below the horizon while none say it is on the other side of the earth. In third grade, half of the students believe that it is on the other side of the earth and only one uses the ‘below the horizon’ explanation. There is also a surprisingly large number of students in both grades who were not able to give clear answers on this topic (three students in first grade and four students in third grade). Among the eighth grade students, most gave the accurate response (the sun is on the other side of the earth). These results are consistent with the results of Vosniadou and Brewer’s study. They found that most first grade students described the sun’s disappearance as the “sun moving down on the ground, whereas most of the older children provided explanations in terms of the rotational movement of the earth” (p. 145).

The related question of what happens to make it daytime reveals an interesting shift. In explaining what happens to make it daytime, over half of the first grade students said that the sun rises, approximately the same percentage as among the eighth grade students who said that the earth turns around to face the sun. None of the students in each grade gave the alternate response. But rather than clearly showing a preference towards one response or the other, the third grade students were spread across a number
of possible responses with only a few students giving either of the responses described above. A quarter of the third grade students believed that the sun and moon switch spots to make day again. Vosniadou and Brewer also found that most of the first grade children explain the day/night cycle in terms of the up/down movement of the sun (and often the moon), while most of the fifth grade children use a rotation of the earth explanation. Similar to the third graders in my study, the third grade students in Vosniadou and Brewer’s study appear to be more broadly dispersed among the variety of explanations, rather than concentrated in one model (up/down movement of the sun) or the other (rotation of the earth). This suggests that while in some areas the third grade students resemble the eighth grade students in their answers about apparent celestial motion, they are not as sophisticated in their mental models of the sun-earth system.

The older students were more accurate in their explanation of what happens to the stars during the daytime. In first grade, only one student knew that the stars are still up in the sky during the day and that the sky is too bright for us to see them. This improves to nearly half of the third grade students and nearly three-quarters of the eighth grade students. In first grade most of the students believe that when the sun comes up the stars either all go down to the other side of the world or go to the moon’s location (which may actually be the same explanation because many believe that the moon is ‘down’ during the day). About one-third of the third grade students also gave one of those responses. The third grade students appear to be in transition in their understanding of the stars daily disappearance since there is such a close split between the students who say the stars all go to the other side of the earth and the students who give the accurate response.
In Vosniadou and Brewer’s study, the students were asked: “Where are the stars during the day?” and “Do the stars move?” Their purpose was to determine whether or not the students think that stars actually move as opposed to apparently move, as was investigated in my study. They found that all 24 students who said that the stars remain up in the sky during the day also said that the stars do not move. Just comparing the students explanations for where the stars are during the daytime shows a similar increase in the number of students who said the stars remain in the sky during the daytime across the grade levels. However, I found that 35% of the first grade students and 25% of the third grade students believe that the stars ‘go to where the moon is’ during the daytime. This concept was not reported in Vosniadou and Brewer’s study. This may be due to the order of questions in my study. I asked the students what happens to the moon when we cannot see it in the sky shortly before asking the students about the stars during the daytime. Because the students associate both the moon and stars with the night and they had the moon concept fresh in their minds, the students I interviewed may have used this explanation. Asking questions in a different order may not have prompted students to answer in this fashion.

Most of the children used the same explanation for the disappearance of the sun and moon from the sky. Vosniadou and Brewer (1994) found the same result in their study of children’s models of the day-night cycle. However, first grade students were significantly more likely to use the same explanation compared to both groups of older students. Over three-fourths of the first grade students used the same explanation while only 45% of the third and 60% of the eighth grade students used the same explanation.
This shift in students using the same explanation for the disappearance of the sun and the moon also coincides with the introduction of logical inconsistencies in the students’ description of these topics. All of the first grade students gave explanations for the disappearance of the sun and the moon from the sky that were logically consistent, primarily using the ‘object goes down’ explanation. Twenty percent of the third grade students and 35% of the eighth grade students gave logically inconsistent answers. This trend was also observed by Vosniadou and Brewer (1994) in their investigation of the logical consistency of elementary students’ mental models of the day/night cycle. They report the following:

It is interesting to note that the likelihood of children’s models being inconsistent increases after the first grade. This finding is in agreement with the hypothesis that the mixed models are a product of children’s failed attempts to reconcile their initial models with the culturally accepted model rather than some overall inability to form coherent models. (Vosniadou & Brewer, 1994, p. 171)

Another way of considering this result is to take a closer look at why first grade students’ models exhibit consistency and simplicity, why students were logically inconsistent at older grades, and what their descriptions of apparent celestial motion can say about the students’ knowledge structures. Vosniadou and Brewer’s claim, that inconsistencies increase as students are learning new scientific ideas and trying to incorporate those explanations into their current conceptions, is supported by the increased frequency of the use of the earth’s rotation and references to the other side of the earth in the older students in this study. In first grade most students’ initial mental models used to describe the day/night cycle fall into one of three possibilities (Vosniadou & Brewer, 1994, p.137):

1. The sun is occluded by clouds or darkness.
2. The sun moves out into space.

3. The sun and the moon move up/down on the ground.

The third model seems to most closely match the descriptions of the sun and moon’s apparent motion as well as their answers to ‘What makes it day?’ found with the first grade students in the present study. The first grade students in my study were far less likely than the older students to describe the sun or moon’s motion as a path that moves continuously across the sky. They were more likely to think of these objects as rising up, spending some time at the top of the sky, and then setting down below the ground.

These ideas, along with the fact that very few of the first grade students used the earth’s rotation in their descriptions, suggest that young children’s initial understanding includes a) the view that sun and moon are the same type of object, exhibiting the same motion, and b) the naïve view of celestial motion that apparent is the same as actual (the sun and moon are actually moving in the sky on a daily basis). This allows the first grade students’ simplistic answers to where the sun and moon are when not visible (the sun and moon are “down”) to be consistent in both their minds and to outside observers interpreting their ideas. Students with initial mental models are not attempting to use different reasoning and descriptions of the sun and moon’s apparent and actual motion. Older children who have been taught to use more scientific explanations (such as the rotation of the earth) may view the sun and moon as exhibiting the same motion because they are applying the same underlying reasoning to both. However, the complexities of understanding and assimilating these new explanations may result in some of the inconsistencies observed. It would be interesting to probe the older, inconsistent, students to determine whether they can recognize these inconsistencies themselves.
disSessa (2006) suggests that what some may argue are logical inconsistencies are not actually in conflict to the students, but rather an expression of our limited description of the students’ actual beliefs. It is possible these older students’ mental models of “rotation” do not fully match the scientific concept of rotation which could allow the students to be internally consistent even if their description sounds inconsistent to someone interpreting their words and actions through the lens of a scientific understanding. Rotation is a difficult concept to master, especially when considering our location on a spherical world and how this affects our view of the sun and moon as the earth spins. Perhaps some students envision the earth turning towards and away from the sun but turning around beneath the moon such that it always remains visible. The students’ understanding of the shape of the earth could also be a factor. Students who have alternative ideas about the shape of the earth may not be able to use the fully scientific explanation of rotation to explain apparent motion in the same way as someone who understands that the earth is a sphere.

**Chapter Summary**

This chapter describes the results of interviews with first, third, and eighth grade students about the knowledge of apparent celestial motion. The analysis reveals several alternative ideas concerning the sun’s apparent motion in general, the comparative features of the sun’s motion across seasons, the changing appearance of the moon, the moon’s apparent motion across, the motion of the stars, and the explanations for the disappearance of the sun, moon and stars. Some concepts appear to change across early elementary school and between elementary and middle school students. Other concepts appear to be relatively consistent in frequency across the grades investigated.
In Chapter 6 I will return to these findings and discuss the implications for instruction on apparent celestial motion through the development of a learning progression for apparent celestial motion.
CHAPTER 5
KINESTHETIC LEARNING TECHNIQUES IN THE PLANETARIUM

Overview

This chapter describes the results of the second half of this dissertation, concerning the degree of success of a planetarium program designed to help students improve their understanding of apparent celestial motion. In this planetarium program, six central concepts of apparent celestial motion were covered using kinesthetic learning techniques (KLTs): the apparent motion of the sun in summer, the apparent motion of the sun in winter, comparison of the path of sun in summer and winter, the apparent motion of the moon across the sky, the apparent motion of the stars and what happens to make it daytime. Additional subjects were covered during the program in which the students observed but did not make any motions to emphasize the topic: the changing appearance of the moon, the visibility of the moon during daytime, and the disappearance of the stars during the daytime. Finally, the students were asked questions during the interviews that were not directly addressed by the planetarium instruction: location of the moon when not visible in the sky and location of the sun at night.

Analysis of the students’ answers to interview questions concerning the topics described above will demonstrate what aspects of apparent celestial motion that this planetarium program is effective in helping to improve student understanding. Both
quantitative and qualitative analyses were performed to answer the following research questions:

1. Do students who participate in a kinesthetic learning program improve their knowledge of the patterns of motion of celestial objects by using kinesthetic learning techniques (KLTs)?
2. Did students learn about addition topics covered in the planetarium program that did not involve kinesthetic motion?
3. Are there other concepts, not linked to the main instruction of the planetarium program that also showed post-visit change?

The analysis of students’ ideas in Study A of this dissertation revealed a wide range of alternative ideas about apparent celestial motion, especially among children in early elementary school when the National Science Education Standards (NSES; NRC, 1996) and Benchmarks for Science Literacy (Benchmarks; AAAS, 1993) recommend students should be learning about these concepts. For this reason, examining students’ ability to improve their understanding will be of great importance for future instructional design.

**Topics Supported By Kinesthetic Learning Techniques**

There are six sub-questions under the first research question that relate to the six concepts covered during the planetarium program using the kinesthetic learning techniques.

1. Do the students demonstrate improved understanding of the apparent motion of the sun across the sky in summer?
2. Do the students demonstrate improved understanding of the apparent motion of the sun across the sky in winter?
3. Do the students demonstrate improved understanding that the path of the sun is shorter and lower in the winter than the summer?
4. Do the students demonstrate improved understanding of the apparent motion of the moon across the sky?
5. Do the students demonstrate improved understanding of the motion of the stars in the night sky?
6. Do the students demonstrate improved understanding of what happens to make it day?
One or two categories were coded for each student from their pre- and post-visit interviews to answer each of the sub-questions. For each category, the students were coded as accurate, partially accurate, or non-normative before and after the planetarium program. A statistical analysis that compared the students’ pre- and post-visit answers for each category shows significant improvement for all questions. The results are shown in Table 5.1. This table also lists the number of students who did not change their accuracy level. However the students who were initially coded as non-normative or partially accurate may have changed ideas within the same accuracy level, such as changing from one non-normative code to another. In the sections below, the results of the analyses of the categories used to answer the above questions will be discussed in detail. Analyses were also performed to look for correlations between student characteristics such as initial knowledge, gender, grade level, and school with improvement in each category.

**Analysis of correlations between student characteristics, initial knowledge, and improvement**

Initial knowledge of celestial motion, gender, grade level, and school were analyzed as possible confounding factors with the level of improvement. The Mann-Whitney non-parametric test for two unrelated samples was used to examine the results of five categories: the path of the sun in summer (Spath), the path of the sun in winter (Wpath), comparison of the length of the sun’s path (Clen), the path of the moon (Mpath), the motion of the stars (MV) and the different stars throughout the night (StDif).
Table 5.1 Results of Wilcoxon signed ranks tests for KLT topics

<table>
<thead>
<tr>
<th>Category</th>
<th>Improved</th>
<th>Regressed</th>
<th>No change</th>
<th>Wilcoxon Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path of the sun in summer (SPath)</td>
<td>39 (61.9%)</td>
<td>1 (1.6%)</td>
<td>23 (36.5%)</td>
<td>-5.72***</td>
</tr>
<tr>
<td>Altitude of the sun in summer (Szen)</td>
<td>41 (65%)</td>
<td>3 (4.8%)</td>
<td>19 (30.2%)</td>
<td>-5.54***</td>
</tr>
<tr>
<td>Path of the sun in winter (WPath)</td>
<td>42 (66.7%)</td>
<td>1 (1.6%)</td>
<td>20 (31.7%)</td>
<td>-5.87***</td>
</tr>
<tr>
<td>Altitude of the sun in winter (Wzen)</td>
<td>42 (66.7%)</td>
<td>1 (1.6%)</td>
<td>20 (31.7%)</td>
<td>-5.89***</td>
</tr>
<tr>
<td>Comparison of sun’s path from summer to winter (Clen)</td>
<td>34 (54.0%)</td>
<td>2 (3.2%)</td>
<td>27 (42.9%)</td>
<td>-5.33***</td>
</tr>
<tr>
<td>Comparison of sun’s altitude from summer to winter (Calt)</td>
<td>35 (55.6%)</td>
<td>4 (6.3%)</td>
<td>24 (38.1%)</td>
<td>-4.46***</td>
</tr>
<tr>
<td>Path of the moon (Mpath)</td>
<td>34 (54.0%)</td>
<td>5 (7.9%)</td>
<td>24 (38.1%)</td>
<td>-4.63***</td>
</tr>
<tr>
<td>Motion of the stars (MV)</td>
<td>26 (41.3%)</td>
<td>2 (3.2%)</td>
<td>35 (55.6%)</td>
<td>-4.11***</td>
</tr>
<tr>
<td>Different stars throughout the night (StDif)</td>
<td>30 (47.6%)</td>
<td>2 (3.2%)</td>
<td>31 (49.2%)</td>
<td>-4.78***</td>
</tr>
<tr>
<td>What happens to make it daytime? (SunD)</td>
<td>17 (27%)</td>
<td>5 (8%)</td>
<td>40 (65%)</td>
<td>-2.29*</td>
</tr>
</tbody>
</table>

*a Change may have occurred within the partially accurate or non-normative categories.

*b One student was not asked this question on both pre- and post-visit interviews (N=62).

No star p>0.05, *p<0.05, **p<0.01, ***p<0.001

First, I examined whether there was a significant difference in the improvement of students who started at different levels of accuracy (non-normative versus partially accurate). The categories concerning the sun’s highest altitude in summer (Szen), highest altitude in winter (Wzen) and the comparison of those altitudes (Calt) were not tested because they are so closely tied to results of Spath, Wpath and Clen, respectively. Students who had an accurate understanding before attending the planetarium program were not included in this comparison because they could not improve. Clen was not
analyzed because students were only coded as either non-normative or accurate (no one was partially accurate). The category for the question of what happens to make it daytime (SunD) was not analyzed because all but two students began as either accurate or non-normative. Analysis showed no significant difference in whether or not the students improved after the planetarium program when comparing students who began as non-normative to those who started as partially accurate for all topics analyzed (Table 5.2).

Table 5.2 Test for correlation between initial knowledge and improvement

<table>
<thead>
<tr>
<th>Category</th>
<th>N</th>
<th>Mann-Whitney U</th>
<th>Z</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPath</td>
<td>62</td>
<td>371.0</td>
<td>-0.882</td>
<td>0.39</td>
</tr>
<tr>
<td>WPath</td>
<td>61</td>
<td>415.5</td>
<td>-0.397</td>
<td>0.69</td>
</tr>
<tr>
<td>Clen*</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>MPath</td>
<td>57</td>
<td>344.5</td>
<td>-0.645</td>
<td>0.52</td>
</tr>
<tr>
<td>MV</td>
<td>44</td>
<td>153.5</td>
<td>-0.538</td>
<td>0.59</td>
</tr>
<tr>
<td>StDif</td>
<td>56</td>
<td>182.0</td>
<td>-1.18</td>
<td>0.24</td>
</tr>
<tr>
<td>SunDb</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

* Clen was not tested because students were only coded as accurate or non-normative.
* SunD was not tested because only two students were coded as partially accurate initially.
* Only students who were coded as non-normative or partially accurate were included in the analysis because students who began as accurate could not improve.

No star p>0.05, *p<0.05, **p<0.01, ***p<0.001

Second, I examined whether gender, grade level or school had any correlation with either the initial accuracy or with improvement after the planetarium program (see Tables 5.3 and 5.4). Analysis showed that grade level had no significant effect on either the students’ initial understanding or post-planetarium improvement except in the students’ initial understanding of the apparent path of the sun in winter. The first grade students were significantly less accurate in their initial description of the winter sun’s path than the second grade students, (Mann-Whitney $U = 269.5$, $Z (N = 63) = -1.97$, $p<0.05$).
Analysis also showed no significant effect of gender on either initial knowledge or improvement except in one instance regarding the understanding of stars. Girls showed significantly more improvement in their ability to describe the concept that we see different stars throughout the night after the planetarium program (Mann-Whitney $U = 366$, $Z (N = 63) = -2.02, p<0.05$). There was no correlation between gender and initial understanding of this topic.

In only one case was the school a factor in predicting initial accuracy and improvement. The first and second grade students from Allensville$^{11}$ were overall more accurate in their understanding of the apparent motion the stars compared to the second grade students from Adventure, (Mann-Whitney $U = 366$, $Z (N = 63) = -2.56, p<0.05$). Because previous analysis had shown no significant difference in the initial knowledge, or improvement, between grades on the topic of the stars’ apparent motion (MV), I then compared just the second grade students between schools. This revealed that the second grade students from Allensville were initially significantly more accurate (Mann-Whitney $U = 172.0$, $Z (N = 47) = -2.44, p<0.05$) but that second grade students from Adventure showed significantly greater improvement after the planetarium program (Mann-Whitney $U =185.0$, $Z (N = 47) = -2.18, p<0.05$).

The factors of grade, gender and school were only found to be significantly related to level of improvement or initial knowledge in isolated cases. This shows that there were no important differences between the school, between first and second grade, or between boys and girls for this study and that these factors did not influence whether or not the students learned from the planetarium program.

$^{11}$ All names of persons, institutions and locations are pseudonyms.
Table 5.3 Test for correlation between population characteristics and initial knowledge

<table>
<thead>
<tr>
<th>Category</th>
<th>Gender&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Grade&lt;sup&gt;a&lt;/sup&gt;</th>
<th>School&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U</td>
<td>Z</td>
<td>p</td>
</tr>
<tr>
<td>SPath</td>
<td>470.0</td>
<td>-0.42</td>
<td>0.68</td>
</tr>
<tr>
<td>WPath</td>
<td>464.0</td>
<td>-0.50</td>
<td>0.62</td>
</tr>
<tr>
<td>CLen&lt;sup&gt;b&lt;/sup&gt;</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>MPath</td>
<td>484.5</td>
<td>-0.16</td>
<td>0.87</td>
</tr>
<tr>
<td>MV</td>
<td>440.0</td>
<td>-0.84</td>
<td>0.40</td>
</tr>
<tr>
<td>StDif</td>
<td>397.0</td>
<td>-1.73</td>
<td>0.08</td>
</tr>
<tr>
<td>SunD</td>
<td>471.0</td>
<td>-0.38</td>
<td>0.71</td>
</tr>
</tbody>
</table>

<sup>a</sup>N = 63.

<sup>b</sup>Clen was not tested because only four students were initially accurate (two girls, two boys). The rest were non-normative.

No star p>0.05, *p<0.05, **p<0.01, ***p<0.001

Table 5.4 Test for Correlation between Population Characteristics and Improvement

<table>
<thead>
<tr>
<th>Category</th>
<th>Gender&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Grade&lt;sup&gt;a&lt;/sup&gt;</th>
<th>School&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U</td>
<td>Z</td>
<td>p</td>
</tr>
<tr>
<td>SPath</td>
<td>476.0</td>
<td>-0.31</td>
<td>0.76</td>
</tr>
<tr>
<td>WPath</td>
<td>415.5</td>
<td>-0.40</td>
<td>0.69</td>
</tr>
<tr>
<td>CLen</td>
<td>374.0</td>
<td>-1.92</td>
<td>0.06</td>
</tr>
<tr>
<td>MPath</td>
<td>451.5</td>
<td>-0.68</td>
<td>0.50</td>
</tr>
<tr>
<td>MV</td>
<td>385.5</td>
<td>-1.73</td>
<td>0.08</td>
</tr>
<tr>
<td>StDif</td>
<td>366.0</td>
<td>-2.02</td>
<td>0.04*</td>
</tr>
<tr>
<td>SunD</td>
<td>381.0</td>
<td>-1.65</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<sup>a</sup>N = 63 except for SunD (N=62).

No star p>0.05, *p<0.05, **p<0.01, ***p<0.001

The apparent motion of the sun in summer

The planetarium program was designed to help the students learn about the apparent motion of the sun during the summer using kinesthetic learning techniques. The students were first asked to use their hands and arms to predict the motion of the sun.

Then the students pointed to the sun as it sat over the north-eastern horizon in the morning and followed its motion as the planetarium instrument caused it to rise and set.

The students also actively pointed to the sun’s highest point and then to the zenith to note
that the sun never passes directly overhead. The students later pointed out the features of
the sun’s path again as well as following its motion along with the moon as they both
rose and set.

During the interviews the students were first asked to point out where the sun was
at different times of day: first thing in the morning, 10 o’clock, lunchtime, in the
afternoon when school gets out, and at the end of the day. Next, the students were asked
to show what the sun does through the entire day to show the complete path of the sun in
one motion. A combination of these two demonstrations was used to describe the
student’s understanding of the apparent daily motion of the sun. The students were also
asked to point to where the sun is at its highest point in the sky and asked if that was
directly overhead. This information was used, along with the previous path shown for the
sun, to categorize their understanding of the sun’s altitude at noon. As with the first,
third and eighth grade students interviewed for Study A, a common alternative idea found
with these students was the belief that the sun is always directly overhead at noon thus
almost all students were either partially accurate or non-normative before the planetarium
program.

The results of comparing pre- and post-instruction understanding of the path of
the sun in summer and the altitude of the sun when highest in summer are shown in
Tables 5.5 and 5.6. In these tables, and similar tables throughout this chapter, the rows
indicate the students’ level of understanding before the planetarium visit. The levels of
understanding are designated: 1 = non-normative, 2 = partially accurate, 3 = accurate.
The columns indicate the students’ level of understanding after the planetarium visit with
the same values of 1, 2 and 3. For example, Table 5.5 shows that six students
demonstrated non-normative paths for the sun (1) before the planetarium program and improved to an accurate path (3) after the program. These tables can be used to identify how many students made each of the possible changes in accuracy.

**Table 5.5 Cross tabulation results - the path of the sun in summer**

<table>
<thead>
<tr>
<th></th>
<th>Spath-Post</th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spath –</td>
<td>1</td>
<td>9</td>
<td>5</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>Pre</td>
<td>2</td>
<td>0</td>
<td>14</td>
<td>28</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9</strong></td>
<td><strong>20</strong></td>
<td><strong>34</strong></td>
<td><strong>63</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Table 5.6 Cross tabulation results - the altitude of the sun in summer**

<table>
<thead>
<tr>
<th></th>
<th>Szen-Post</th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Szen –</td>
<td>1</td>
<td>11</td>
<td>8</td>
<td>22</td>
<td>41</td>
</tr>
<tr>
<td>Pre</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>11</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12</strong></td>
<td><strong>15</strong></td>
<td><strong>36</strong></td>
<td><strong>63</strong></td>
<td></td>
</tr>
</tbody>
</table>

Students showed significant improvement on their ability to demonstrate the accurate path of the sun after the planetarium program (Wilcoxon Signed Ranks Test, $Z = -5.72$, p<0.001). One common, pre-instruction belief was that the sun’s path is a straight line across the sky, through the zenith, rising and setting 180 degrees apart. This concept was coded as partially accurate. This idea accounts for 67% percent of the answers given prior to the planetarium visit. After the planetarium visit, 67% of those students improved to an accurate demonstration of the sun’s path, while only 33% retained the partially accurate concept. The students who changed from partially accurate to accurate did so by learning in the planetarium that the sun does not pass directly overhead.

For students who demonstrated paths significantly different from the sun’s actual path, such as students who showed sharp turns in their paths, showed the sun rising and
setting in the same place, or demonstrated an indistinct path for the sun, the difference between the motion they observed in the planetarium and their initial understanding was greater. Of the 20 students who demonstrated a non-normative idea prior to the planetarium visit, 53% improved to either partially accurate (four students) or accurate (six students). This percentage of improvement from the non-normative students is not significantly different from the percentage that improved from partially accurate to accurate.

Students who improved from partially accurate to accurate learned that the sun does not pass directly overhead. Students who improved from non-normative to a higher level learned a new way of describing the sun’s apparent motion. Thus the students who initially had a very different path for the sun learned both a new path and that the sun does not pass directly overhead, if they improved to an accurate description. Perhaps it is not surprising that students were able to learn both of these concepts during the program because they were using kinesthetic learning techniques to follow both of these aspects of the sun’s motion at the same time.

Only Cory, a second grade boy, showed a regression by moving from an accurate to partially accurate answer in the post-visit interview. During his pre-visit interview he demonstrated the sun passing smoothly across the sky through 80 degrees altitude (he was the only student to demonstrate a correct path in his pre-instruction interview). In the post-instruction interview he demonstrates the path of the sun going through the zenith. However, when asked where the sun is when it is highest in the sky he pointed to 80 degrees and said that this is not directly overhead. Perhaps Cory was not thinking
about the specifics of what he was demonstrating. He may not have been paying
attention to the same features of the sun’s path as I, an expert, was observing.

As mentioned above, much of the improvement in the student’s understanding of
the path of the sun was going from the concept that the sun passes directly overhead to
learning that even in summer the sun is never overhead in Michigan. In their initial
interview only five students showed the sun not passing through the zenith and indicated
verbally that the sun was not directly overhead. However, all of those students, except
for Cory, demonstrated a non-normative path for the summer sun. As shown in Table
5.1, there was significant improvement on the students’ knowledge of the sun’s highest
altitude in the summer (Wilcoxon Signed Ranks Test, $Z = -5.54$, $p<0.001$). This
suggests that by tracing the sun’s motion across the dome of the planetarium and
comparing the sun’s highest altitude with the zenith is an effective way of demonstrating
that the sun does not pass directly overhead.

The apparent motion of the sun in winter

The planetarium program built on the students’ previous experience of having
observed the motion of the sun in the summer several times during the program before
addressing the sun’s apparent motion in winter. At the end of the program, the sun was
moved to the correct alignment for the first day of winter. The students once again
predicted the path of the sun before following that path with their arms as the planetarium
instrument showed its motions. The differences between the sun’s path in summer and
winter were specifically compared during the program.

After the section of the interview covering the motion of the sun in summer, the
students were asked the same questions but now in terms of the winter sun’s path. Just as
with the improvement in students’ knowledge of the sun’s path in summer, there was significant improvement in their understanding of the sun’s path in winter (Wilcoxon Signed Ranks Test, Z = -5.87, p<0.001).

Table 5.7 The path of the sun in winter

<table>
<thead>
<tr>
<th>Wpath - Post</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wpath - Pre</td>
<td>1</td>
<td>8</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>10</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>16</td>
<td>38</td>
<td>63</td>
</tr>
</tbody>
</table>

Table 5.8 The altitude of the sun in winter

<table>
<thead>
<tr>
<th>Wzen - Post</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wzen - Pre</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>7</td>
<td>51</td>
<td>63</td>
</tr>
</tbody>
</table>

The distribution of possible changes to the accuracy level for each student in the Wpath and Wzen categories are given in tables 5.7 and 5.8. Sixty-five percent of the students who demonstrated non-normative paths during their pre-instruction interview improved to an accurate (nine students) or partially accurate path (six students). Of those six students who demonstrated partially accurate paths in the post-instruction interview, three demonstrated two different paths during their post interview: a non-normative path first and then accurate path. The students who gave non-normative answers first were pointing out where the sun was at specific times of day. The accurate paths were shown when asked to show the entire path of the sun throughout the day rather than stopping at particular points during the day. Perhaps these students are still experiencing some conflict between their previous ideas and what they learned in the planetarium. They
may be working through the ideas in the post interview or they may not understand the
ordered sequence of times that were used to prompt the students during the interview.

Of the eight students who retained non-normative ideas about the winter sun’s
path across the sky, three students (second grade) did show some improvement in their
understanding. For example, Alex initially does not demonstrate a complete path for the
sun, saying that the sun is “gone” in the morning and remains at about the same altitude
from noon through the afternoon. After the planetarium program, Alex shows the sun
rising straight up to the zenith then turning sharply before setting straight down. Because
it is not a smooth curve (it has a sharp turn in the path) it is not counted as accurate or
partially accurate, but it is closer to the accurate path than his previous demonstration.
The other five students (four in first grade students and second grade student)
individually demonstrated the same ideas in both summer and winter pre-/post-visit
interviews across a range of non-normative ideas. The complexities of motion across a
three-dimensional representation of the sky may have been too challenging for some very
young students.

Only one student demonstrated a less accurate answer in his post-instruction
interview. Darius, a second grade student, showed the sun following a smoothly curved
path through the zenith in his pre-visit interview. In his post-visit interview he
demonstrated the sun rising straight up to 80 degrees then setting only 10 degrees from
where it rose. Darius showed a similar pattern when asked about the summer sun’s path,
showing a path that rose and set on opposite sides of the sky in his pre-instruction
interview and moving to a straight-up-and-down model in his post-instruction answers. It
is unclear why his understanding of the path of the sun would change in this manner.
Twenty-six percent of those initially coded as partially accurate (ten students) retained a partially accurate understanding of the path of the sun in winter. The partially accurate category includes both the otherwise accurate path that passes through the zenith and the mixed response (demonstrating two paths for the sun, one of which is accurate or partially accurate). Nine of the students showed the same inaccurate pattern in both interviews: a smooth path through the zenith (seven students) or a mixed response (two students). Only one of these students changed within the category, moving from demonstrating the path through the zenith in his pre-instruction interview to a mixed response in his post-instruction interview. This fraction of students who did not show a change in their answers may reflect the degree of engagement among the students in the planetarium.

Just as in the summer, the main change in students’ understanding of the sun’s path in winter was in learning about the change in altitude of the sun in winter – specifically the idea that it does not pass directly overhead. The students showed significant improvement in this area of understanding (Wilcoxon Signed Ranks Test, $Z = -5.95$, $p<0.001$). The number of students who expressed an accurate understanding that the sun’s path passes below the zenith in the winter improved from 20% to 81% of the students. Five students retained a non-normative idea in the post-instruction interview. Of these students, four continued to show the sun passing through the zenith (prior to the planetarium program, students were also coded as showing the sun making a loop around the zenith or not showing enough of the path to make a determination). One student had difficulties showing a complete path of the sun in both pre- and post-instruction
interviews, though he did show the sun going through the zenith in the winter in his post-visit demonstration.

This large sample of first and second grade students revealed that many students are clearly influenced by their experiences living through a few winters. Seven students (11%) said during their pre-visit interviews that the sun was not up in the morning or the afternoon. Two students (one of the previous seven plus an additional student) gave this type of response in the post-instruction interview. Tim’s answer is typical of these students:

I: Where's the sun first thing in the morning in the winter?
Tim: Uhm, not really out.
I: What about later in the morning, around 10 o'clock in the morning, would the sun be out?
Tim: Hmm, no.
I: Not up in the sky?
Tim: He agrees.

Further, nine students (14%; including one of the eight above) used clouds, or the general grayness of the sky, to explain why they could not show where the sun was in the sky in winter, during the pre-visit interview. Two students also used these ideas in post-instruction answers (both students used clouds or snow in their pre-instruction interviews as well). Charles, a second grade student, did not think you can see the sun in the winter though was able to indicate where it would be, behind the clouds:

I: Where would the sun be first thing in the morning?
Charles does not say anything and is probably covering the flashlight.
I: Is it in the sky?
Charles: It's in the sky but it's not showing because the clouds are covering it. Probably right there. (He points to just above the horizon.)
I: Where would it be at 10AM?
Charles: Right here but still not showing. (He points to 50 degrees altitude.) It depends on how much snow there is and how cold it is.
I: So maybe sometimes you might see the sun?
Charles: Yeah.
In comparison, none of the students mentioned clouds while talking about the summer sun’s path. And only three students did not show the sun in the sky during part of the day in the summer (one seemed confused during these questions, one said the sun is covered by the moon at the end of the day, and the third said the sun is below the horizon in the afternoon).

**Comparison of the sun’s path between summer and winter**

During the planetarium program the students used kinesthetic learning techniques to learn the sun’s apparent motion in summer and winter. When the students followed the path of the sun in the winter they were asked to compare its rising and setting position of the sun to summer as well as the difference in the altitude at noon.

To demonstrate the accurate comparison of the sun’s path in summer and winter the student needed to show that the sun rises and sets farther apart (by at least 45 degrees) and reaches a higher altitude in summer compared to winter. The students showed significant improvement in their understanding that the sun’s path is lower and shorter in the winter compared to the summer (Wilcoxon Signed Ranks Test, $Z = -5.33$, $p<0.001$). The distribution of how students’ ideas changed from pre- to post-instruction is shown in Table 5.9.

<table>
<thead>
<tr>
<th>Table 5.9 Comparison of the sun’s path from summer to winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clen - Post</td>
</tr>
<tr>
<td>Clen - Pre</td>
</tr>
<tr>
<td>Pre</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
Table 5.10 Comparison of the sun’s altitude from summer to winter

<table>
<thead>
<tr>
<th></th>
<th>Calt - Post</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Calt -</td>
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</tr>
<tr>
<td>Pre</td>
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</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
</tr>
</tbody>
</table>

The idea that the path of the sun is different in summer and winter was not something previously understood by these children, as was also found with the first, third and eighth grade students interviewed for Study A. Initially, only four students demonstrated paths that correctly compared the sun’s path across the seasons. Three of those students were coded as accurate after the program but Rhonda, a second grade student, demonstrated a less accurate comparison between the summer and winter paths during her post-visit interview. During her pre-interview, both paths passed through the zenith but the winter path was 60 degrees shorter. In her post-visit interview, she showed identical paths for the sun in summer and winter.

I: Is that the same as it was in the summertime?
Rhonda: A little bit higher.
I: Is there anything else different between the summer and the winter?
Rhonda: The earth turns a little bit different so that's why it's so cold and darker.

After the planetarium program she suggests that the difference between summer and winter has to do with the turning of the sun. She did not mention this in her pre-instruction interview. It is possible that the difference she demonstrated initially was not an intentional difference in the two paths.

Of the remaining students, 59% (35 students) improved to an accurate comparison of the path of the sun in summer and winter. Trent initially demonstrated that the sun’s path is the same length in summer and winter, though moving in the opposite direction.
After the planetarium program he was able to demonstrate both visually and verbally his improved understanding. During the summertime interview questions he starts to show paths of different lengths. This prompted the following discussion:

I: So does (the sun) do something different some of the time?
Trent: Different ah, seasons it goes bigger or smaller.
I: Makes smaller arcs on the sky?
Trent: Yeah.
I: OK, so in the summer is it bigger or smaller do you think?
Trent: I think it's the biggest arc it makes.

In the winter interview he also indicated the same idea by describing the sun’s path as “the smallest arc.”

A large part of the significant improvement in the students’ abilities to compare the sun’s path in summer and winter was to compare the noontime altitude of the sun (Wilcoxon signed ranks test, $Z = -4.46$, $p<0.001$). In the pre-instruction interview, only 21% of the students demonstrated that the sun has a higher altitude in summer compared to winter. In their post-instruction interview this increased to 63% of the students demonstrating the correct comparison.

**Table 5.11 Comparison of the direction of the sun’s path in summer and winter**

<table>
<thead>
<tr>
<th>Direction - Post</th>
<th>A</th>
<th>B</th>
<th>C</th>
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<tr>
<td>Direction - Pre</td>
<td>A</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>36</td>
<td>43</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>2</td>
<td>6</td>
<td>49</td>
<td>63</td>
</tr>
</tbody>
</table>

A = not comparable, B = shifted by more than 45 degrees, C = opposite direction, D = same direction

Some students showed the direction of the sun changing between summer and winter. The distribution of students who demonstrated this concept before and after the planetarium program is shown in Table 5.11. While the majority of students before and
after the planetarium program (68% and 78%, respectively) are able to accurately show that the sun’s motion is in the same direction in both summer and winter, there are still several students with non-normative ideas on this topic. This was not unexpected as students interviewed for Study A also showed the sun moving in the opposite directions between summer and winter.

However, in this study, more students demonstrate the sun’s path switching direction after the planetarium program than before (six students compared to three students). If the students who shifted the sun’s path by more than 45 degrees are included, then 13% of the students demonstrate an inaccurate comparison of the sun’s direction across the seasons after the planetarium program compared to 8% before the program. This includes four students who showed the accurate comparison before the planetarium program. A closer examination of these students’ answers does not reveal any clues that might explain this change. Perhaps this shows that some children at this age are not aware of directions in the same way that adults remember directions. The students may not have been intentionally switching directions.

**The apparent motion of the moon**

During the planetarium program the students observed and traced the apparent motion of the moon. After the students learned about the path of the sun, they followed the motion of both the sun and the crescent moon as they rose and set. Next they followed the apparent motion of the first quarter moon and the full moon.

Similar to the path of the sun, the students were coded as accurate if their path for the moon was a smooth curve across the sky that does not path through the zenith. If they did show the moon’s path going through the zenith it was coded as partially
accurate. There was also a large range of non-normative ideas concerning the apparent motion of the moon including that the moon circles around the sky without rising or setting or that the moon does not move during the night. The students showed significant improvement in their understanding of the path of the moon after attending the planetarium program (Wilcoxon Signed Ranks Test, \( Z = -4.63, p<0.001 \)).

Table 5.12 The path of the moon

<table>
<thead>
<tr>
<th>Mpath-Pre</th>
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<th>2</th>
<th>3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mpath-Pre</td>
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<td>2</td>
<td>9</td>
<td>21</td>
</tr>
<tr>
<td>Pre</td>
<td>2</td>
<td>11</td>
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<td>36</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>16</td>
<td>35</td>
<td>63</td>
</tr>
</tbody>
</table>

The distribution of how students’ ideas about the path of the moon changed from before to after the planetarium visit is shown in Table 5.12. Half of the students (52%) who began with non-normative ideas improved their understanding. Jon improved from a non-normative description in his pre-instruction interview to a description coded as accurate. Before the planetarium he was not sure how to describe the motion of the moon:

Jon: Usually the moon I don't think it changes position. Every night I think it changes. But usually it's right around here. In the middle.
I: Does the moon move during the night?
Jon: Maybe, uh, I don't know really. I think we learned that in first grade. I can't remember. It might... it'll stay.

After the planetarium program he is able to demonstrate the path of the moon as a smooth curve across the sky.

I: Is it moving in the sky?
Jon: Uhm, sort of. Cause I see it here and then I see it…
I: Somewhere else? Or gone?
Jon: Gone
I: Show me what it would be doing.
Jon: It would be <*> the same thing as the sun.
Jon shows the moon following a smooth path across the sky, through about 70
degrees altitude at its highest with rise and set position 180 degrees apart.

Sixty-four percent of the students with partially accurate ideas improved their
understanding to accurate in their post-visit interviews. Just as with learning about the
path of the sun, there was no significance in the difference in the percentage of students
who showed improvement between the students who were initially non-normative versus
partially accurate.

Fourteen percent of the students (9 students) demonstrated the non-normative idea
that the moon seems to circle around the sky rather than rising and setting. Five of these
students verbally connect this with their knowledge of the orbit of the moon. Only two
students, Ellen and Kyle, demonstrated similar paths for the sun. Ellen demonstrated the
sun’s path beginning at the zenith, circling around, and then ending where it started – at
the zenith. This was similar to how she demonstrated the motion of the moon. When
asked what the will happen to the moon when the sun comes up, she responds: "It comes
back into the clouds and you can't see it and then, then <*> its night time again. It does
the same thing. It goes back out of the clouds and then..." Kyle demonstrated the sun
circling around the zenith in both summer and winter in his pre-planetarium interview.
However, during his pre-planetarium visit interview about the moon he said that the
moon does not appear to move. It is during his post-planetarium interview that he
demonstrates the moon’s motion as circling around the sky. He says "Ah, yeah, it goes -
orbits around the sun."

Darren, a second grade boy, also demonstrates the moon moving around the sky
in a circular pattern and connects this with the moon’s orbit (but does not show the same
motion for the sun). He describes both the apparent motion of the moon and his understanding of the actual motion of the sun, earth and moon in his pre-instruction interview:

I: Does the moon move in the sky during the night?
Darren: Uh, yes it follows the earth. It goes <***> - it goes like this. Goes around the earth, <***> going around.
I: What if we went outside just after it got dark out, where do you think the moon would be?
Darren: Uhm, the moon would be?
I: Where in the sky would we see the moon?
Darren: Right there, then there, then <***> there and there [He demonstrates the moon moving in a circle around the sky at about 20 degrees altitude.]
I: Oh, is that how it moves around in the sky?
Darren: Yep, for us it does. That's how it looks for us. But in reality <***> the sun it goes around like that's the earth. Goes around the earth and goes around the sun. [He uses the flashlight to show a spiraling motion around the zenith.]

Four students demonstrated that the moon circles around the zenith, without also mentioning about the moon’s orbit. These students demonstrated the same motion as other students who also related this motion to the moon’s actual motion. Jared, a second grade student, showed the moon moving back and forth across the sky without setting during his pre-instruction interview. In his post-instruction interview he demonstrated the moon circling around the zenith:

Jared: Uhm, it's going around like.
I: What if we went outside and looked at the sky? We see the sun rise and set. Does the moon rise and set?
Jared: Uhm, no.
I: So is the moon always up there in the sky?
Jared: Yes.

Of the nine students who indicated that they believe the moon moves in a circular pattern around the sky, only second grade student Rhonda demonstrated this in both pre- and post-instruction interviews. Two students, Ellen and Darren, mentioned this idea in a pre-visit interview and then improved to an accurate path of the moon in the post-visit
interview. The remaining six students have a range of ideas in their pre-visit interviews (including not moving at all and showing different paths for the moon in winter) before demonstrating this motion in their post-visit interview.

It is not clear why more students tried to connect the moon’s orbit with its apparent motion in the sky in the post-visit interviews. I did mention briefly that the moon is in orbit around the earth but we spent far more time following the moon’s path across the sky than on that idea. It is unlikely that this was the result of a specific teacher or teachers covering the orbit of the moon in class because these nine students were from six different classrooms across both schools. This description of the moon’s motion was also described by some students interviewed in Study A.

The apparent motion of the stars

During the planetarium program the students observed the stars rising and setting during the planetarium. They pointed to where new stars appeared to rise and other stars appeared to set. They also pointed and followed a star’s motion to see that some stars set while others stay in the sky. They observed the rising and setting of the stars over several nights.

The concept of apparent stellar motion was probably the most challenging for the students. Children at this age are likely to have had very little opportunity to observe the night sky, let alone notice that the stars’ positions change over the course of the night. Even more challenging is the concept that we see different stars as the night progresses or that we could ever be able to recognize this change due to the vast number of seemingly indistinguishable stars. In their pre-visit interviews, six students simply said that they did not know rather than attempt to give an answer. In other area, students attempted to give
some form of answer. The planetarium program was successful in helping many of the students learn about the motion of the stars. The results revealed a significant improvement in their knowledge of the motion of stars (Wilcoxon Signed Ranks Test, $Z = -4.11, p<0.001$), as well as a significant improvement in their understanding that we see different stars throughout the night (Wilcoxon Signed Ranks Test, $Z = -4.78, p<0.001$).

Table 5.13 Motion of the stars

<table>
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<th></th>
<th>MV - Post</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>MV- Pre</td>
<td>15</td>
</tr>
<tr>
<td>Pre</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
</tr>
</tbody>
</table>

Table 5.14 Different stars throughout the night

<table>
<thead>
<tr>
<th></th>
<th>StDif - Post</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>StDif Pre</td>
<td>20</td>
</tr>
<tr>
<td>Pre</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
</tr>
</tbody>
</table>

Forty-one percent of the students improved their understanding of the motion of the stars, 56% of students did not change in accuracy, and 3% regressed (see Table 5.13). Most of this improvement in the students’ knowledge was from students who did not think that stars moved or that only special stars move (coded as non-normative) to either partially accurate (demonstrating some understanding that the stars move) or accurate (showing the stars moving across the sky in a smooth pattern). Fifty-six percent of the students who began as non-normative (19 of 34 students) improved to partially accurate or accurate after planetarium instruction. Seventy percent of the students with partially
accurate understanding initially (7 of the 10 students) improved to accurate understanding in the post-visit interview. Only two students indicated a less accurate idea after the planetarium program.

Andy is one example of a second grade student who came to the planetarium program with very little understanding of motion of the stars but improved to a more accurate understanding after the planetarium program. The following excerpt is from his pre-instruction interview:

I: Do the stars move in the sky at night?
Andy: Well, someone told me that the stars were like, little planets but they’re like, like things that they can't, like they can't land on and stuff.
I: Let's pretend that the flashlight's a bright star and stuff. Let's say you see it there just after sunset when it gets dark out. Where will that star be at midnight?
Andy: I think it would be just like there <*>.
I: So would it stay in the same place?
Andy: Yes.
I: Do we see the same stars in the sky all night long?
Andy: I don't know ‘cause I’m still asleep at midnight.
I: That's a good point. What happens to the stars at the end of the night when the sun comes up?
Andy: I kind of see a little bit in the morning but when it gets towards the afternoon the stars fade away and go down and stuff.
I: Are there still stars up there in the sky during the daytime?
Andy: Uhm, I don't know. I don't really see stars <***>. I don't think there is stars.

In his post-visit interview, he brought up the stars while answering questions about the moon. He also mentioned a star (Antares, the “heart” of the Scorpion) that we used as part of the instruction in the planetarium:

I: Does the moon seem to move in the sky at night?
Andy: Well yeah, and the stars do too.
I: Oh, well show me what the moon does first.
Andy: The moon comes up and… Do you want it to be the Christmas time or the summer time?
I: Uhm, how about Christmas time?
Andy: Like that and then all the stars are following it <***>.
I: So the moon goes up and then it goes down. And the stars do the same thing?
Andy: Uh-huh (yes)
I: Stars the same. What does it do in the summertime, the moon?
Andy: That and the stars are doing the same thing but it last long and longer and longer, and longer, gets lower. (He shows the same path but this time a little higher and longer, still not through zenith.)
I: Does the moon always go down when the sun comes up?
Andy: Well, the moon would going down it, the stars are following with it. Is there another light thingy? And moving like that and the stars are doing it with it but it, the sun does the same things it do. But the sun is going slower than the moon. So and then the, and when the moon goes down the sun was popping up in right there.
I: Do we see the same stars in the sky all night long?
Andy: Well, some of the stars aren't going down because the uhm, uhm, what's that one star called, the heart?
I: Arcturus, oh -- the heart, Antares the Heart of the Scorpion.
Andy: Yeah, it stays up longer.
I: So do the stars rise and set like the sun does?
Andy: Yeah. They come down eventually.

It is not all together surprising that many of the students did not improve their understanding of these topics given how much more challenging it is to consider the apparent motion of a whole system of stars that rise and set throughout the night. Many students held onto their initial alternative ideas about the motion of the stars and the concept of seeing different stars throughout the night. Twenty-two percent of the students held onto both non-normative ideas – that the stars do not move and that we do not see different stars through out the night. And not all of the students who learned the motion of the stars during the night also learned that we see different stars throughout the night. Eleven percent of the students who improved their knowledge of the star’s motion still did not believe that we see different stars throughout the night.

One interesting case was Robbie, a second grade student, who claimed both that the stars do not move but that we see different stars throughout the night in his post-visit interview. In his pre-visit interview:
I: Do the stars move in the sky at night?
Robbie: Just one.
I: What one?
Robbie: The wishing one.
I: Oh, the wishing star. But the rest of the stars, they don't move.
I: Let's say that the flashlight is a star up there in the sky after dark. Will it still be there after midnight?
Robbie: Hmm, yeah, I guess so.

In his post-visit interview, some of his statements seem to contradict each other:

I: Do the stars seem to move in the sky at night?
Robbie: No?
I: Do we see the same stars in the sky all night long?
Robbie: No.
I: Why not?
Robbie: Because the earth moves around and we can see different stars.
I: Ah the earth turns around and we see different stars?
Robbie: Yeah.
I: You showed me the sun rising and setting and the moon rising and setting. Do the stars rise and set?
Robbie: No.
I: If we see that star later at night, will it still be in the same place?
Robbie: Yeah.

It unclear how Robbie reconciles the idea that the stars do not move with the earth moves allowing us to see different stars. This suggests that some children do not see the logical necessity that if the earth moves this means that the stars will appear to move from our perspective.

**What happens to make it daytime?**

The concept of “What happens to make it daytime?” combines aspects that were covered in the planetarium using KLTs and some that were not. One accurate way of describing what happens to make it daytime is to show the sun rising. However, the scientifically correct explanation would also include explaining that the earth rotates to face the sun. It was covered using KLTs because we observed and traced the sun rising.
to start a new day. I also described what was happening as the ‘earth turning to face the sun again.’ I initially coded both ‘the sun rises’ and ‘the earth turns around to face the sun’ as accurate responses to the question “What happens to make it daytime again?”

Two students gave the partially accurate responses that indicated the sun was in the sky but not how it got there, such as Catherine’s response, “All I know of that we see the sun when we wake up. And it’s daytime again.” There was a significant improvement in the students’ responses to this question, Wilcoxon Signed Ranks Test, $Z=-2.29, p<0.05$.

Because the planetarium program was primarily focused on the earth based perspective, I initially assumed that the improvement in this area was from students who changed from a non-normative response to saying that the sun rose to make it daytime, rather than saying that the earth turns around to face the sun. To test this hypothesis, I separated out the two types of accurate responses and assigned the value 3 to ‘the sun rises’ and the value 4 (more accurate) to ‘the earth turns around to face the sun.’ The distribution of answers before and after the planetarium program are broken down by these four levels of accuracy and listed in Table 5.15. There was still a significant improvement in student responses after the planetarium program with the sequence described above, Wilcoxon Signed Ranks Test, $Z = -2.53, p <0.02$.

### Table 5.15 What happens to make it daytime?

<table>
<thead>
<tr>
<th></th>
<th>SunD – Post$^b$</th>
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</tr>
</thead>
<tbody>
<tr>
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<td>$^1$</td>
<td>$^3$</td>
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<tr>
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<tr>
<td>Total$^a$</td>
<td>21</td>
<td>24</td>
</tr>
</tbody>
</table>

$^1$ = non-normative idea; $^2$ = sun is in the sky (does not explain how); $^3$ = sun rises; $^4$ = earth turns around to face the sun

$^a$ One student was not asked this question.

$^b$ Idea 2 was not observed among any of the students post-instruction.
Before the planetarium program, half of the students interviewed (50%) had non-normative ideas about what happens to make it daytime. After the planetarium program, nearly a third of those students (29%) changed their answer to say that the sun rises while only 10% changed to saying that the earth rotates to face the sun in the morning.

Marshall, a second grade student, is an example of a student who changed from a non-normative response to describing the sun as rising to give us daytime again. Before the planetarium program, he says to make it daytime again “The moon would have to turn around ‘cause usually we don't see a crescent moon in the morning. And then the sun would uhm, ah, go down a little bit so then we could see the sun.” After the planetarium program he response “Well, the sun would kinda appear [points to horizon] and kind rise up and do its normal thing and <*>... kinda disappears when it goes down [He demonstrates the entire path of the sun across the sky during the day until it sets].”

Ariana, a second grade student, is an example of a student who shifts from a non-normative understanding to a clear description of the earth rotating to make it daytime for us. In her pre-instruction interview she describes the motion as the sun actually moving to the other side of the earth:

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

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

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

In addition to the students who improved from the non-normative level, both partially accurate students improved from just saying that the sun is in the sky to saying that the sun rises to make it daytime. Four students shifted their explanation from saying that the earth rotates around to face the sun before the planetarium to saying that the sun rises after the planetarium program, including Sandy, a second grade student. During her pre-instruction interview she says “The earth is gonna, the earth is gonna spin up like. It's like the flashlight is the earth, like spins. Not like that but just goes like this but the flashlight is doing like.” After the program her response is:

Sandy: Here comes the sun up! (She uses the flashlight to show the sun rising up the dome).
I: Is that what makes it daytime again?
Sandy: Yeah, but it doesn't go that fast.

These results suggest that the planetarium program was more successful in promoting the description of the sun’s apparent motion as the answer to this question, over the concept of the earth’s rotation. This was expected because the students used their own motion to emphasize the sun rising as the cause of daytime.

Summary

Students showed significant improvement across all topics covered using the kinesthetic learning techniques. Further, on the topics that the students are likely to be more familiar with (the motion of the sun and moon) more than half of the students showed improvement of their understanding. For the motion of the stars at night, more than 40% of the students improved their abilities to describe and demonstrate the concepts.
A large part of the improvement seen in the path of the sun in summer and winter was from students who learned that the sun does not pass directly overhead but otherwise were able to describe the path of the sun as a smooth curve before the planetarium program. A large fraction of the students initially showed non-normative paths for the sun in both summer and winter. Over half of these students were able to give an accurate or partially accurate demonstration of the path of the sun after the planetarium program.

Only a few of the students were able to accurately demonstrate the difference between the sun’s path in summer and winter before the planetarium program. This improved greatly with over half of the students improving to an accurate comparison after the planetarium program. The students who improved by learning that the sun is lower in the sky in the winter and that the rise and set positions are closer together. Before the planetarium program most students demonstrated the same path in summer and winter. However, one aspect of the comparison did not improve after the planetarium program. More students showed that the direction of the sun’s motion in winter is not aligned with its direction in summer after the planetarium program than before. It is unclear why this change occurred.

The students showed a similar pattern of improvement in their understanding of the apparent path of the moon across the sky as with the sun. More than half of the students who were not coded as accurate before the program improved, with a larger fraction of the partially accurate students improving compared to the non-normative students. Some of the students with non-normative paths for the moon brought up the orbit of the moon in their answers.
Only 30% of the students were able to describe and give a demonstration of the apparent motion of the stars before attending the planetarium program. Most of the students did not think that the stars moved during the night. Thus for this topic most of the improvement was not just in the nature of the motion they described but that they learned the stars do seem to move across the sky during the night. Over half of the students (59%) that began as non-normative or partially accurate were able to give an accurate response about the stars’ apparent motion after attending the planetarium program.

Most of the students also did not think that we see different stars throughout the night, as would be expected if the students believe that the stars do not appear to move. There was significant improvement in the students’ understanding of this topic as well, but there remained students after the planetarium program that were able to describe the stars as appearing to move across the sky but did not believe we see different stars throughout the night.

Finally, students improved in their ability to explain what happens to make it daytime. While some students improved to say that the earth rotates to face the sun in the morning, more students improved to describe the sun as rising in the morning. This was expected because the students tracked the sun’s motion rising using kinesthetic learning techniques.

**Topics Not Supported By Kinesthetic Learning Techniques**

There are four sub-questions under the second research question that relate to four topics covered during the planetarium program that did not use kinesthetic learning techniques.
1. Do the students demonstrate improved understanding of the concept that the appearance of the moon changes on the order of days or weeks?
2. Do the students demonstrate improved understanding of the concept that the shape of the moon does not appear to change over the course of one night?
3. Do the students demonstrate improved knowledge of the moon’s appearance in the daytime sky?
4. Do the students give an improved explanation for the stars location during the day?

For each category, the students were coded as accurate, partially accurate, or non-normative before and after the planetarium program. The Wilcoxon signed ranks test used to compare the students’ pre- and post-visit answers for each category shows significant improvement for all questions (see Table 5.16). In the sections below, the results of the analysis of the categories used to answer the above questions will be discussed in detail. An analysis was also performed to look for correlations between student characteristics such as initial knowledge, gender, grade level, and school with improvement in each category.

**Table 5.16 Results of Wilcoxon Signed Ranks tests for Non-KLT topics**

<table>
<thead>
<tr>
<th>Category</th>
<th>Improved</th>
<th>Regressed</th>
<th>No change</th>
<th>Wilcoxon Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Time for the Appearance of the Moon to Change (Mapp)</td>
<td>20 (32%)</td>
<td>2 (3%)</td>
<td>40 (65%)</td>
<td>-3.84***</td>
</tr>
<tr>
<td>Shape of the Moon During One Night (MCN)</td>
<td>15 (26%)</td>
<td>1 (2%)</td>
<td>42 (72%)</td>
<td>-3.50***</td>
</tr>
<tr>
<td>Moon Visible During the Day (Mday)</td>
<td>13 (20.6%)</td>
<td>3 (4.8%)</td>
<td>47 (74.6%)</td>
<td>-2.48*</td>
</tr>
<tr>
<td>Stars Location During the Day (StDay)</td>
<td>19 (30%)</td>
<td>2 (3%)</td>
<td>42 (67%)</td>
<td>-3.50***</td>
</tr>
</tbody>
</table>

*a Change may have occurred within the partially accurate or non-normative categories.
*b 62 students were asked this question on both pre- and post-visit interviews.
*c 58 students were asked this question on both pre- and post-visit interviews.
No star p>0.05, *p<0.05, **p<0.01, ***p<0.001
Analysis of correlations between student characteristics, initial knowledge, and improvement

The correlation between initial knowledge of the categories and improvement was not analyzed for the categories concerning the moon’s changing appearance, the visibility of the moon during the day, and the stars’ location during the day (Mapp, MCN, Mday and StDay). For the categories Mapp and MCN, the students were coded as only accurate or non-normative so there could be no correlation between initial knowledge level and improvement. The category of the moon’s appearance during the daytime (Mday) was coded as accurate (Yes, we can see the moon during the day), partially accurate (No…sometimes), and inaccurate (No). There was no significant effect of initial knowledge (non-normative versus partially accurate) on the students’ improvement of understanding in the Mday category (Mann-Whitney $U (N = 15) = 21.0$, $Z = -1.20$, $p>0.05$). Prior knowledge had no effect on the whether the students’ learned that the moon appears in the daytime sky. For the category ‘knowledge of the stars location during the day’ (StDay), only three of the students were coded as partially accurate. Thus, there were not enough students to compare the influence of being non-normative versus partially accurate on whether the students improved or not.

The student characteristics of gender, grade level, and school were analyzed as possible confounding factors. The Mann-Whitney non-parametric test for two unrelated samples was used to examine the results of the changing appearance of the moon (Mapp and MCN), the moon during the day (Mday) and the stars’ location during the day (StDay). Results are listed in Tables 5.17 and 5.18. Gender, grade level, and school were not found to be a significant effect on predicting initial accuracy or improvement except in one case. Students from Adventure Elementary were significantly more likely
to improve their knowledge of the moon’s visibility in the daytime (Mday) compared to the students from Allensville, Mann-Whitney \( U (N = 63) = 341.0, Z = -2.60, p = 0.01. \)

All nine of the students at Adventure who began as non-normative or partially accurate gave the correct response after the planetarium program. Of the students from Allensville, four students improved, two students remained non-normative, and three students regressed from the accurate category. However, there were a small percentage of students involved in computing this statistic because only 25% of the students gave answers that improved or regressed after the planetarium program.

### Table 5.17 Test for correlation between population characteristics and initial knowledge

<table>
<thead>
<tr>
<th>Category</th>
<th>Gender</th>
<th></th>
<th></th>
<th></th>
<th>Grade</th>
<th></th>
<th></th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U</td>
<td>Z</td>
<td>p</td>
<td>U</td>
<td>Z</td>
<td>p</td>
<td>U</td>
<td>Z</td>
</tr>
<tr>
<td>Mappa(^a)</td>
<td>433.5</td>
<td>-1.02</td>
<td>0.31</td>
<td>286.5</td>
<td>-1.70</td>
<td>0.09</td>
<td>402.0</td>
<td>-1.322</td>
</tr>
<tr>
<td>MCNb(^b)</td>
<td>417.5</td>
<td>-0.99</td>
<td>0.32</td>
<td>314.0</td>
<td>-1.00</td>
<td>0.32</td>
<td>419.0</td>
<td>-0.81</td>
</tr>
<tr>
<td>Mday(^a)</td>
<td>462.0</td>
<td>-0.61</td>
<td>0.54</td>
<td>337.0</td>
<td>-0.83</td>
<td>0.41</td>
<td>388.0</td>
<td>-1.74</td>
</tr>
<tr>
<td>StDi(^a)</td>
<td>398.0</td>
<td>-1.52</td>
<td>0.13</td>
<td>358.5</td>
<td>-0.31</td>
<td>0.75</td>
<td>377.5</td>
<td>-1.64</td>
</tr>
</tbody>
</table>

\(^a\) N = 63.
\(^b\) N = 62.

No star \( p > 0.05 \), * \( p < 0.05 \), ** \( p < 0.01 \), *** \( p < 0.001 \)

### Table 5.18 Test for correlation between population characteristics and improvement

| Category | Gender | | | | Grade | | | School |
|----------|--------|--------|--------|--------|--------|--------|--------|
|          | U      | Z      | p      | U      | Z      | p      | U      | Z      | p      |
| Mapp\(^a\) | 466.5 | -0.20  | 0.84   | 353.0 | -0.29  | 0.77   | 453.0 | -0.26  | 0.80   |
| MCNb\(^b\)  | 407.5 | -0.22  | 0.83   | 313.5 | -0.21  | 0.84   | 388.0 | -0.50  | 0.62   |
| Mday\(^c\)  | 470.0 | -0.45  | 0.65   | 361.0 | -0.31  | 0.76   | 341.0 | -2.60  | 0.01\(*\) |
| StDi\(^a\)  | 492.5 | -0.04  | 0.97   | 290.0 | -1.65  | 0.10   | 480.0 | -0.02  | 0.99   |

No star \( p > 0.05 \), * \( p < 0.05 \), ** \( p < 0.01 \), *** \( p < 0.001 \)

\(^a\) N = 62.
\(^b\) N = 58.
\(^c\) N = 63.
Length of time for the appearance of the moon to change

In the planetarium program, the students observed the crescent moon as it appeared to move across the sky along the same path as the sun. During this time, the phase of the moon did not change. The planetarium was then set to show us the sky “three days in the future” so that the students would get the opportunity to see what the phase of the moon would look like after it had time to shift into the first quarter phase. This was followed by jumping ahead by a week to observe the motion of the full moon across the sky. These events during the planetarium program were designed to show the students that the shape of the moon does not appear to change noticeably during the time that it take so move across the sky, but rather over a longer period of time.

During the interviews, the students were asked to draw pictures of what the moon looks like in the sky. This lead into questions about how long it takes for the shape of the moon to appear to change. The students were either coded as accurate (the phase of the moon changes between more than a night and no more than a month), or inaccurate (the phase of the moon changes in less than a night or more than a month). There was a statistically significant improvement in the number of students who learned the accurate length of time for the appearance of the moon to change, Wilcoxon signed ranks test, $Z = -3.84$, $p<0.001$. However, because the Wilcoxon signed ranks test is a comparison of improvement versus regression it ignores the number of students who did not show change. Table 5.19 gives a more descriptive view of the change in students’ understanding, before and after the planetarium program.
Table 5.19 Length of time for the phase of the moon to change

<table>
<thead>
<tr>
<th></th>
<th>Mapp-Post</th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Mapp-Pre</td>
<td>1</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>41</td>
<td>62a</td>
</tr>
</tbody>
</table>

*One student was not asked this question during one of his interviews because we were interrupted by a fire drill.

While only two students changed from accurate to inaccurate, nearly the same number of students remained non-normative (31%), remained accurate (34%) and improved to an accurate response to this question (32%). The remaining 3% of the students regressed. Though nearly a third of the students did not improve their understanding, the number of students who gave an accurate answer doubled after attending the planetarium program.

Cory is an example of a second grade student who improved his understanding of the length of time it takes for the apparent shape of the moon to change. During the interviews I asked the students to draw pictures of the moon. Before the planetarium program he drew a circle. He then said that sometimes it appeared to be “a half” and drew a line bisecting his circle. When I asked him how long it takes to change from one shape to the other he responded, “I thought like 7 hours or so.” After the planetarium program, Cory draws the shapes of a half moon, full moon, and a crescent. In response to how long it will take for the shape of the moon to change, he answered “A week. Or maybe about 3 days I think.”

**Shape of the moon during one night**

In addition to asking the students how long it takes for the appearance of the moon to change, I asked them directly if they thought the shape of the moon would
appear to change during one night. Students were accurate if they said that the appearance of the moon would not change at all or not change enough for us to notice during the night. There was a significant improvement in students’ answers after attending the planetarium program, Wilcoxon Signed Ranks Test, $Z = -3.50, p<0.001$. Twenty-six percent of the students improved while 72% did not change accuracy. This improvement represents half of the students that were initially non-normative. Most students gave short yes or no-type answers.

Table 5.20 Shape of the moon during one night

<table>
<thead>
<tr>
<th></th>
<th>MCN-Post</th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>MCN-</td>
<td>15</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Pre</td>
<td>1</td>
<td>27</td>
<td>28</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>42</td>
<td>58$^a$</td>
</tr>
</tbody>
</table>

$^a$ Some students were not asked this question during both interviews.

Location of the moon during the day

The students were asked whether or not the moon can be seen during the daytime. During the planetarium program, the students specifically followed the both moon and sun’s motion with their arms across the daytime sky at the same time. The students were coded as inaccurate if they said “No” we cannot see the moon during the day and accurate if they said “Yes” we can see the moon during the day. Just as with the first and third grade students interviewed for Study A, some students said “No… sometimes.” These students were coded as partially accurate. Students in the partially accurate category seem to have some level of confusion of this subject as if two concepts are in conflict for them – the idea that the moon is up only at night and that perhaps they have actually seen the moon during the daytime. There was a statistically significant improvement in the students’ understanding of this concept as seen by the number of
students who improved compared to those who regressed after the planetarium program, Wilcoxon Signed Ranks Test, \( Z = -2.48, p < 0.05 \).

**Table 5.21 Can we see the moon during the day?**

<table>
<thead>
<tr>
<th>Mday - Post</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mday - Pre</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>45</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>2</td>
<td>58</td>
<td>63</td>
</tr>
</tbody>
</table>

1 = No; 2 = No…sometimes; 3 = Yes

Table 5.21 shows the distribution of students’ knowledge of the moon in the daytime sky before and after the planetarium program. Though the majority of the students already knew that the moon is visible during the daytime sky (76%), after the planetarium program all but two of the students were accurate (92%). As mentioned above, there was a significant difference in the improvement between the two schools, favoring students from Adventure Elementary over Allensville. Some of this may be because of the small number of students who improved or regressed (16 students).

Another possibility is that the students from Adventure had the opportunity to observe the moon in the daytime sky after their pre-instruction interview while the students at Allensville did not have the same opportunity owing to the phase of the moon or the weather.

Of the nine students who said “No” we cannot see the moon during the day before the planetarium program, seven changed to the accurate response after instruction.

Before the planetarium program, Mandy, a second grade student from Adventure, said that we can never see the moon during the day. After the planetarium program she spoke of seeing the moon in the sky: “I saw it twice on Sunday <***> on yesterday and I think Saturday.” None of the other students who changed their response mentioned seeing the
moon, though many of the other initially accurate students did mention seeing the moon in the daytime sky during their interviews.

**Location of the stars during the day**

During the planetarium program, the students were able to see the stars both during the simulated “daytime” and “nighttime.” This was because the lights used to make the sky appear blue for day are not bright enough to drown out the stars projected by the planetarium instrument onto the sky (so that the audience members’ eyes will remain dark adapted). During the program, we talked about why we cannot see the stars in the real daytime sky compared to the planetarium sky, even though they are still there. The students were also able to observe that the stars seem to move across the sky during the night and then to continue to rise and set during the day just as the sun does.

During the interviews, the students were asked ‘What happens to the stars when the sun comes up?’ A student coded as accurate indicated that the stars are still in the sky during the day, such as Faith’s post-instruction response: “Well it's to bright to see them. They're still there but you just can't see them.” A few students who said that the stars are still in the sky during the day were coded as partially accurate because they gave an inaccurate explanation for why we cannot see the stars during the day. All but one of these students said that clouds were the reason we cannot see the stars during the day. Allison, a second grader, seemed to imply that the sun only has a certain amount of light to give out. She had earlier stated that sometimes we cannot see the moon even though it is still in the sky because it is not getting any light from the sun:
I: What's going to happen to the stars when it's about time for the sun to come up again?
Allison: Uhm, you can't see them for the same reason you can't see the moon. Because they need light and the other planets need light. And it's not that the sun can do for more for the moon. Because the sun still needs to give heat and light to the other side of the world. So that they can have a summer and a winter too.
I: So, the stars are still up there during the daytime?
Allison: Yeah.

Allison remained partially accurate after the planetarium program. She said that during the day the stars are “still up there” but does not give a clear explanation for why we cannot see them.

Table 5.22 Location of the stars during the day

<table>
<thead>
<tr>
<th>StDay-Pre</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>8</td>
<td>1</td>
<td>17</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
<td>32</td>
<td>34</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>3</td>
<td>50</td>
<td>63</td>
</tr>
</tbody>
</table>

Slightly more than half of the students gave an accurate response to this question before the planetarium program (54%). After the planetarium program this increased to 79%, a significant improvement (Wilcoxon signed ranks test, \( Z = -3.50, p<0.001 \)).

Twenty-seven percent of the students improved from an inaccurate to an accurate response. Alex, a second grade student, moved from a typical non-normative idea (all the stars go down at the end of the night) to the accurate description after the planetarium program. In his pre-instruction interview, Alex used his knowledge that the sun is a star to explain his ideas:

I: What happens to the stars at the end of the night when the sun comes up?
Alex: Uhm, first stars are out like the sun's a star. One star will stay up and it’s probably going to be the bright star and all the other stars will go down.
I: They'll all go down but one bright one will stay up there?
Alex: The brightest one which would be the sun. No wait, all the stars are in space <*> sun but the sun's on the other side of the earth so then it comes around like this and all the other stars go down. The other stars won't go down they go just to the other side of the earth.

After the planetarium program, Alex gives an accurate response: “They're still up in the sky only the sun is so bright uhm, you can't see the other stars”

In the case of Daisy, another second grade student, her answer became much richer resulting an accurate coding in the post-instruction interview. Prior to the planetarium program she said that during the daytime the stars are on the “other side of the world.” Following the planetarium program her answer begins in the same way but she extends it to include scientifically accurate concepts:

Daisy: Uhm, the other side of the world because the uhm, earth rotates. Stars probably stay in the same spot.
I: OK, the stars stay in the same spot and the earth rotates. So it's daytime now, are there any stars up there in the sky right now?
Daisy: Yeah, you just can't see them very well.
I: How come?
Daisy: Because it's sunny out and the stars are little, not that sunny as the sun.

Amanda, in second grade, also seemed to take what she knew before the planetarium program and incorporate the new ideas in her post-instruction response. Before the planetarium program she said:

Amanda: I think they go farther away, to the other side.
I: The other side…
Amanda: We can't see them.
I: Other side of the world?
Amanda: Yeah

After the planetarium program her response was:

I: When the sun comes up, what happens to the stars?
Amanda: They go down with the, uhm, moon.
I: So during the daytime, like right now, are there any stars up there in the sky?
Amanda: There is. The sun is too bright.
Her response suggests that she believes both that the stars going down with the moon as well as stars remaining in the sky while the sun makes it too bright for us to see them.

**Summary**

Even though the students did not use kinesthetic learning techniques to learn these topics they showed significant improvement in their understanding of the changing appearance of the moon, the moon’s appearance in the daytime sky, and the location of the stars during the day. Improvement ranged from 21% of the students improving their understanding of the moon’s appearance in the daytime sky to 32% of the students improving their knowledge of how long it takes for the shape of the moon to seem to change (Mapp). There were also a large percentage of students who were accurate in these topics before the planetarium program.

Half of the students who had non-normative ideas about how long it takes for the appearance of the moon to change improved to an accurate response after the planetarium program. Most of this improvement was from students who initially thought that the apparent shape of the moon can change noticeably during one night improved to responding that we would not notice a change in the moon’s appearance in a night. In the case of the location of the moon during the day, 86% already knew that we could see the moon during the day some of the time (including the partially accurate responses). Therefore, despite being statistically significant, this result is not as powerful since it affected so few students. Finally, more than half (65%) of the students who began with non-normative ideas about what happens to the stars when the sun rises improved to give an accurate description after the planetarium program.
Topics Not Directly Covered in the Planetarium Program

There were two sub-questions under the third research question that related to topics that were, at most, covered indirectly during the planetarium program.

1. Do the students demonstrate improved understanding of the location of the moon when we cannot see it?
2. Do the students demonstrate improved understanding of the location of the sun at night?

Both of the questions in this section correspond directly to a question asked during the interview. The students were coded as accurate, partially accurate, or non-normative before and after the planetarium program. The Wilcoxon signed ranks test was used to compare the students’ pre- and post-visit answers for each category. There was no improvement for either question (see Table 5.23). In the sections below, the results of the analyses used to answer the above questions will be discussed in detail. An analysis was also performed to look for correlations between student characteristics such as initial knowledge, gender, grade level, and school with improvement in each category.

Table 5.23 Results of Wilcoxon Signed Ranks tests for topics not covered in the program

<table>
<thead>
<tr>
<th>Category</th>
<th>Improved</th>
<th>Regressed</th>
<th>No change a</th>
<th>Wilcoxon Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moon’s Location When We Cannot See It (MoNV) b</td>
<td>11 (17.7%)</td>
<td>6 (9.7%)</td>
<td>45 (72.6%)</td>
<td>-1.30</td>
</tr>
<tr>
<td>Sun’s Location at Night (SunN) b</td>
<td>7 (11%)</td>
<td>6 (10%)</td>
<td>49 (79%)</td>
<td>-0.23</td>
</tr>
</tbody>
</table>

a Change may have occurred within the partially accurate or non-normative categories.

b One student was not asked this question on both pre- and post-visit interviews (N=62).

No star p>0.05, *p<0.05, **p<0.01, ***p<0.001
Analysis of correlations between student characteristics, initial knowledge, and improvement

Initial knowledge of the topics, gender, grade level, and school were analyzed as possible confounding factors. The Mann-Whitney non-parametric test for two unrelated samples was used to examine how these factors might relate to the sun and moon’s location when we cannot see them. Results are shown in Table 5.24. There was no association found between initial knowledge level and the students’ improvement on these topics. Thus students’ prior knowledge about the sun and moon’s location when we cannot see them did not predict whether or not the students’ understanding would improve or regress.

Table 5.24 Test for correlation between initial knowledge and improvement

<table>
<thead>
<tr>
<th>Category</th>
<th>N*</th>
<th>Mann-Whitney U</th>
<th>Z</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoNV</td>
<td>38</td>
<td>137.5</td>
<td>-0.689</td>
<td>0.50</td>
</tr>
<tr>
<td>SunN</td>
<td>28</td>
<td>90.0</td>
<td>-0.35</td>
<td>0.72</td>
</tr>
</tbody>
</table>

* Only students who were coded as non-normative or partially accurate were included in the analysis because students who began as accurate could not improve. No star p>0.05, *p<0.05, **p<0.01, ***p<0.001

Gender, grade, and school were not found to predict the students’ initial knowledge or improvement for the topics analyzed in this section except in one case (see Tables 5.25 and 5.26). There was a statistically significant difference in the initial knowledge of the sun’s location at night between the first and second grade students. The second grade students were more likely to have an accurate or partially accurate understanding of the sun’s location at night than the students in first grade, Mann-Whitney $U (N = 63) = 257.0$, $Z = -2.09$, $p<0.05$. It is likely that the second grade students have had more opportunities to learn about the day and night cycle and that the earth faces away from the sun at night in school, compared to first grade students.
Table 5.25 Test for correlation between population characteristics and initial knowledge

<table>
<thead>
<tr>
<th>Category</th>
<th>Gender U</th>
<th>Gender Z</th>
<th>Gender p</th>
<th>Grade U</th>
<th>Grade Z</th>
<th>Grade p</th>
<th>School U</th>
<th>School Z</th>
<th>School p</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoNV</td>
<td>466.5</td>
<td>-0.42</td>
<td>0.67</td>
<td>325.0</td>
<td>-0.87</td>
<td>0.39</td>
<td>398.5</td>
<td>-1.24</td>
<td>0.21</td>
</tr>
<tr>
<td>SunN</td>
<td>399.0</td>
<td>-1.47</td>
<td>0.14</td>
<td>257.5</td>
<td>-2.09</td>
<td>0.04*</td>
<td>389.0</td>
<td>-1.43</td>
<td>0.15</td>
</tr>
</tbody>
</table>

aN = 63.
No star p>0.05, *p<0.05, **p<0.01, ***p<0.001

Table 5.26 Test for correlation between population characteristics and improvement

<table>
<thead>
<tr>
<th>Category</th>
<th>Gender U</th>
<th>Gender Z</th>
<th>Gender p</th>
<th>Grade U</th>
<th>Grade Z</th>
<th>Grade p</th>
<th>School U</th>
<th>School Z</th>
<th>School p</th>
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</thead>
<tbody>
<tr>
<td>MoNV</td>
<td>457.0</td>
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<td>0.70</td>
<td>358.5</td>
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<td>433.5</td>
<td>-0.53</td>
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</tr>
<tr>
<td>SunN</td>
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<td>0.39</td>
<td>275.5</td>
<td>-1.78</td>
<td>0.08</td>
<td>401.0</td>
<td>-1.35</td>
<td>0.18</td>
</tr>
</tbody>
</table>

aOne student was not asked this question on both pre- and post-visit interviews (N = 62).
No star p>0.05, *p<0.05, **p<0.01, ***p<0.001

Where is the moon when we can’t see it?

During the planetarium program the students observed the moon rising and setting. I also described the motion they were observing as being the result of the rotation of the earth. During the program the students stood up and rotated around pretending to be the earth while they faced towards and away from the moon. However we did not specifically discuss the location of the moon when we cannot see it with respect to the shape of the earth.

An accurate response for this question would have been to say that the moon is on the other side of the earth when we cannot see it. Saying that the moon was “down,” “below the ground” or “set” was counted as partially accurate. If the student gave two conflicting answers including an accurate response, they were coded as partially accurate as well. A range of responses were coded as non-normative such as saying that the moon is behind the sun or the clouds but otherwise still up in the sky. There was not a
significant improvement in the students’ responses after the planetarium program as may be expected given that this was not a major goal of the planetarium program, Wilcoxon signed ranks test, \( Z = -1.30, p>0.05 \).

Table 5.27 shows that the majority of students remained at the accuracy level they began with for this topic (71%). While not a significant difference, nearly twice as many of the students improved (11 students) as regressed (6 students).

Table 5.27 Where is the moon when we can’t see it?

<table>
<thead>
<tr>
<th></th>
<th>MoNV-Post</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>MoNV-</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MoNV-</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Ariana, a second grade student, improved from non-normative to accurate. In her pre-instruction response she focuses on not being able to see the moon during winter.

I: Do we ever not have the moon up in the sky?
Ariana: Yeah.
I: Where is it then?
Ariana: It's like the winter and you can't, can barely see the moon, only in like at midnight or like ten, you could see the moon.
I: And why can't we see it at other times?
Ariana: Because it's the moon is white?
I: Oh, yeah, and the sky is white?
Ariana: Yeah, so it's blending in.

After the planetarium program Ariana’s answer improves, though it suggests she still considered the fact that she does not see the moon very often in the winter sky:

I: Where is the moon when we can't see it?
Ariana: Uhm, like we can't see it it's on the other side of the world.
I: Other side of the world?
Ariana: Yeah, and in the winter time too.
While the most of the students who were either non-normative or accurate before planetarium program remained at their initial level of accuracy, many of the students initially partially accurate either improved or regressed (see Table 5.27). Trent, a second grade boy, is an example of a student who regressed from partially accurate to a non-normative response. In his initial interview, he said that when we cannot see the moon it “goes behind the clouds or coming up the edge of, going around.” This implies that he thinks the moon has gone behind something, such as the ground, when it is not visible. In his post-instruction interview he suggested that the moon is “blocked by a cloud or the sun.” During his pre-instruction interview he showed the moon rising and setting but in his post-interview he demonstrated the moon circling around the sky, never rising or setting. This change in his answer to where the moon goes when it is not visible is consistent.

Of the 19 students who expressed non-normative ideas about the moon’s location when not visible only 7 improved. A concept such as this one would perhaps be better addressed by instruction that deals directly with the earth and moon’s shape and actual motion. The planetarium program was designed to primarily address the moons apparent motion when it is visible in the sky.

**Where is the sun at night?**

This topic was not specifically covered during the planetarium program. During the program, the students followed the path of the sun down below the horizon until it set. I described this motion as being the result of the earth’s rotation. We did not specifically discuss the concept of the ‘sun on the other side of the earth’ during the planetarium program. An accurate answer to this question requires some level of understanding of the
shape of the earth and that sometimes our part of the earth is not facing towards the sun.
A student was coded as partially accurate for this question by indicating the sun is either
below the ground/horizon or somewhere else on earth (without indicating that this is on
the other side of the earth). There was not a significant improvement in the students’
understanding of this concept after attending the planetarium program, Wilcoxon Signed
Ranks Test, \( Z = -0.23, p>0.05 \).

Table 5.28 Where is the sun at night?

<table>
<thead>
<tr>
<th></th>
<th>SunN-Post</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1</td>
</tr>
<tr>
<td>SunN-Pre</td>
<td>11</td>
</tr>
<tr>
<td>Pre</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>13</td>
</tr>
</tbody>
</table>

Over three-fourths of the students (77%) did not change their level of accuracy
after attending the planetarium program. Approximately the same number of students
improved (13%) as regressed in accuracy (10%). Tasha, a second grade student, is an
example of one of four students who regressed from an accurate answer to a partially
accurate answer. In her pre-planetarium program interview she says: “It's on the other
side of the world because when we're awake and it's like daytime the other side of the
world is nighttime. And then when it's daytime on the other side of the world its night
time for us.” After the planetarium program she said that at night the sun is "on the other
side of the country." This change in answer is consistent with her explanation of where
the moon is when it is not visible. In her pre-instruction interview she said that the moon
is "Over to the other side of the world." In her post-interview answer changed to: "On the
other side of the country because when we're awake the other side of the country is
asleep. And when we're asleep the other side of the country is awake." Perhaps for her, “the other side of the country” is the same thing as the other side of the world. Lucy, a first grade student, also gave an answer that suggests her understanding has not actually changed, just the way she is expressing herself. Before the planetarium program:

Lucy: It would be like right here (she points down) on the other side of the world and then it will travel up again.
I: To make it daytime?
Lucy: Uh-huh (yes) but it takes a long time and goes very slow.

After the planetarium program, she retains the idea of down but does not elaborate. She simply said “It’s below us.”

Three of the students improved from non-normative to partially accurate. Charlotte, a second grade student, initially said that at night the sun “disappears.” After the planetarium program, and though she did not really explain where the sun is, her description of what happens improves: “It like sun set.” Wendy, a first grade student, also improved from non-normative to partially accurate. Initially she said that the “moon and stars are in front of it” at night. After the planetarium program her answer changed to reflect a similar concept as Charlotte: "I know where the sun is. It's down under the ground. Down, ‘cause it's not on the ground. It must be under the ground. Cause it doesn't go up. It goes down."

This question, where is the sun at night, is a challenging question to assess in the setting used for this study. While other concepts were tested both verbally and with the students’ demonstration, the location of the sun at night would be more accurately assessed using models or drawings because this concept also deals with the students’ understanding of the shape of the earth. Some of the variation seen in students’ answers
(comparing before and after instruction) may have been reduced if additional methods of assessment were used in this topic.

Summary

The questions answered in this section relate to knowledge of the shape of the earth. A complete and accurate answer to where the moon is when we cannot see it and where the sun is at night require the ability to imagine that the earth is a sphere and that our part of the earth can face away from the moon and sun at times. These interview questions were not designed to deeply probe the students overall mental model of the shape of the earth, whether it is the earth or the sun that is moving, or the nature of that motion. The planetarium program and this study are focused on the apparent patterns of celestial motion not the shape of the earth or the actual motion of these objects.

The lack of transfer effects found between the instruction on apparent celestial motion and these disappearance concepts may also reflect the conceptual differences between understanding the shape of the earth and the motion of celestial bodies. Children may not see a conflict between their non-normative understanding of the shape of the earth and their description of celestial motion. A child who imagines that the earth is flat like a pancake may still describe the sun as rising in the morning, traveling across the sky, and setting on the other side of the sky to go down below the pan-cake shaped earth. Or perhaps children’s knowledge is more tenuous. They may not be making the connections between their mental model of earth’s shape and the motion they are describing.

These questions were asked as they provide an extension to the apparent motions that the students had described. As could be predicted, because the planetarium program
was not designed to improve the students understanding of the location of the sun and moon when they are not visible, there was no improvement seen for either of these topics. It is worth noting that there was also no significant regression in students who gave accurate responses before the program. The planetarium program did not have a negative impact on these topics.

Chapter Summary

In this chapter I answered three research questions relating to the change in students’ knowledge of apparent celestial motion after attending a planetarium program involving kinesthetic learning techniques. Students used their own motion to predict and follow the apparent motion of the sun in summer and winter, the moon during the day and at night, and the stars at night. The findings of this study and proposed explanations will be discussed below.

Research question 1

The first research question addressed the use of kinesthetic learning techniques to help students improve their understanding of the apparent motion of the sun, moon, and stars. All topics that were addressed using the kinesthetic learning techniques showed highly significant improvement after the planetarium program. First, this suggests that kinesthetic learning techniques are an effective way for children to learn about apparent celestial motion in a planetarium. Second, this shows that children in first and second grade are capable of learning the patterns of celestial motion.

There are several ways that instruction in the planetarium program can account for the significant improvement seen in the students’ understanding of celestial motion.
First, the kinesthetic learning techniques engaged the students as active participants using their own motion and observations. Thus rather than passively observing the patterns of motion, the students used their own motions to make predictions and compare those predictions with the motion demonstrated in the planetarium. This also helped minimize distractions by focusing the students’ attention on the pertinent features of the patterns of motion. The students were perhaps more aware of the changing direction of the sun and moon’s motion as they moved across the sky by their own shifting direction. They also experienced the continuous motion of the objects as they moved across the sky, with their own kinesthetic experience, rather than staying at the top of the sky through out the day (or night).

Some students may have come to the planetarium with weakly developed understanding of the patterns of celestial motion. These students may have only had some basic ideas about the sun, moon and stars behavior rather than fully developed descriptions of these patterns of motion. They may have improved because the program provided them with a way to describe and visualize these motions that matched some of their prior concepts, such as the sun being up in the sky during the day, and down at night. Other students may have had more clearly defined mental images of the patterns of apparent celestial motion, such as the students who were coded as partially accurate. These students may have improved because the kinesthetic learning techniques in combination with their observations provided a clear enough alternative description to replace or modify their previous description.

The kinesthetic learning techniques may have helped the students learn in the planetarium in other ways beyond just focusing their attention on the patterns of motion.
Some of the power of kinesthetic learning techniques may derive from students learning to encode information in multiple modalities. Dual Coding theory (Clark & Paivio, 1991; Paivio, 1986) assumes that there are two different cognitive processing systems: one that specialized to process language and one that processes information concerning nonverbal phenomena. Students would therefore be processing the verbal description of the sun, moon and stars’ apparent motion separately from the kinesthetic experience as well as the visual representation. Students were learning to associate their memory of the motions they performed with the verbal codes for apparent celestial motion and the visual images they observed in the planetarium. Improvement could therefore be the result of a combination of sensory, visual, and auditory stimulus. Students, who may have come to the planetarium program with only a poorly developed concept of the apparent motion of the sun, were able to connect a visual image of the sun moving across the sky in a smooth pattern with the kinesthetic representation of moving their arm in that same pattern. This combination of experiences relating to these topics may have also improved understanding because now they are not relying on just one way of recalling when given an auditory prompt, but two: kinesthetic and visual.

This does bring up the point of how the students were assessed. In order to demonstrate that they had learned these topics, the students displayed their knowledge by demonstrating many of the same motions as they learned by following the sun, moon and stars in the planetarium – though this time the students were in control of the motion of these objects. Part of learning about the patterns of celestial motion was learning how to correctly demonstrate them. There was limited transfer assessed in this task because the
students were not asked to transform these ideas into a 2-D representation or only a verbal description.

In Chapter 2, I proposed that the kinesthetic learning techniques in celestial motion would also be used to promote cognitive conflict. Druyan (1997) investigated children using kinesthetic-cognitive conflict to learn about concepts of length, balance, and speed. She found that situations which incorporated kinesthetic aspects that conflicted with the children’s prior knowledge were more effective than visual or social methods of conflict. The conflict in the present study was in the difference between how the students initially represented the apparent patterns of motion – with both visual and kinesthetic representations – and how they were prompted to demonstrate these motions with their arms and bodies. In this theory, students would recognize a conflict in their present understanding of the patterns of motion with the model presented in the planetarium and chose to adopt the new idea to replace or modify the old. This was probably most helpful to students who held beliefs that greatly contradicted the experience in the planetarium, such as not believing that the sun or moon’s motion was continuous or that the sun and moon rise and set on opposite sides of the sky.

In addition to providing the students with kinesthetic memories that match with the visual patterns of motion, it is important to recall the setting of the instruction. The planetarium is designed to recreate the daytime and night time sky with the images of the celestial objects that are believable replicas of the real objects. Because the instructional setting is designed to clearly represent the real sky, it may be that this enhanced the students’ connections to their prior experiences. The environment may have also contributed to the students’ engagement in the instruction by immersing them in a three-
dimensional experience. Beyond the kinesthetic experience is the importance of the visual experience to build up a repertoire of visual representations of these concepts that can be returned to and explored when referenced at a later time.

It is important to note that there were no post-planetarium activities on these topics in the classroom. The post-planetarium visit interviews took place about one week (average of 6.9 days) after the planetarium program. Thus the improvement measured was not based on immediate recall, but on the students’ knowledge several days after participating in the 45-minute program.

Of those topics covered using the kinesthetic learning techniques, the students showed the most improvement on the topics relating to the sun’s apparent motion and the moon’s apparent motion. On each of these subjects, more than half of the students demonstrated improved understanding of the patterns of motion of these objects. Some of the students improved by learning that the sun and moon do not pass directly overhead by both observing the difference and following the sun and moon’s motions with their hands. Other students improved by learning that the sun and moon both display a similar path across the sky, rather than one of the many non-normative descriptions of the sun and moon’s apparent motion demonstrated before the planetarium program. The students’ prior knowledge about the sun and moon may have helped them learn these new ideas about celestial motion by providing knowledge to build upon. This may have included such knowledge as the sun ‘goes up and down’ during the daytime and that the moon rises and sets as well.

Within the area of the sun and moon’s apparent motion, there was one topic that appears to have been more challenging for the students to learn compared to the others:
the comparison of the length of the sun’s path in summer to winter. Even though over half showed an accurate path after the planetarium program, there remained one-third (33%) of the students who did not show that the sun’s path is longer in summer than winter. Learning to correctly compare the sun’s path across seasons requires keeping track of where the sun rises and sets and the difference in those positions from summer to winter. Perhaps this difference is too far removed from their prior knowledge of the motion of the sun for some of the students to learn this in addition to also learning how to accurately demonstrate the sun’s path across the sky. This topic also requires that the students pay closer attention to directions in order to judge how far across the sky the sun has crossed. This additional complexity may also be beyond some of the students’ previous experience and abilities. Perhaps more improvement would occur if additional work was done on this comparison in the planetarium program than was included for this study.

There was less improvement in the students’ knowledge of the patterns of motion of the stars, compared to the sun and the moon. Less than half of the students improved their understanding of the motion of the stars (41%) and that we see different stars throughout the night (48%). About a third of the students gave non-normative responses in their post-instruction interviews on these two topics (27% and 33%, respectively). This result is not surprising because understanding the motion of the stars is a more challenging subject than the motion of the sun or the moon. First, children are likely to have less prior knowledge about the stars in terms of observing them and studying their properties, compared to the sun and moon. Without a foundation of prior knowledge to build on, the students are limited in how they will be able to incorporate
new descriptions of the stars into their current understanding. Second, the children’s prior knowledge of stars may conflict with what they observe in the planetarium. If the students believe that the stars are fixed and never moving, the idea that the stars appear to move smoothly throughout the night may be too incongruent with their beliefs to accept. This is related to understanding the cause of the stars’ apparent motion: the earth’s rotation. Without knowledge of why the stars appear to move, the pattern of the stars’ apparent motion may not make sense to the students, making it difficult for them to assimilate the patterns of the stars’ motion into their knowledge of stars. While there was significant improvement observed in children’s understanding of the apparent motion of stars, those students who did not improve may have shown greater improvement if they had studied some of the basic ideas relating to the appearance of the stars prior to going to the planetarium in order to set in place concepts on which to build these new ideas about motion.

I also examined the concept of ‘What happens to make it daytime?’ as one of the topics covered using the kinesthetic learning techniques. If the answer ‘the earth turns to face the sun’ is considered to be more accurate than ‘the sun rises’ then 45% of the students improved in this topic while only 26% of the students remained non-normative. It is interesting to note that nearly the same number of students improved from initially non-normative responses to saying that the sun rises (11 students) as said the earth turns to face the sun (9 students). The students were taught using kinesthetic learning techniques that the sun rises in the morning; they pointed to the sun where it would rise and then followed it up as the sky brightened. However, the topic of the earth turning to face the sun was taught by a verbal description of what was happening to make the sun
appear to rise up into the sky. Perhaps the students that showed improvement in this second manner did so because they had previously learned about the rotation of the earth and were now able to connect that idea more firmly with the concept of ‘daytime’.

Research question 2

The second research question addressed additional topics of apparent patterns of celestial motion that were not taught using kinesthetic learning techniques. A portion of these topics were assessed during the pre- and post-instruction interviews, including the length of time that it takes for the apparent shape of the moon to change, the visibility of the moon during the daytime, and the location of the stars during the day. The students showed significant improvement on these topics which suggests both that students at this age are capable of learning these concepts and that the use of instruction in a planetarium is a successful strategy.

This improvement may be attributed the level of engagement encouraged by the use of kinesthetic learning techniques and the visually stimulating environment. The students were learning about these topics while simultaneously learning about other topics using kinesthetic learning techniques. For example, while the students followed the motion of the sun and the crescent moon’s motion at the same time (by pointing at each with a different hand) they were also observing that the moon is visible in the daytime sky. Similarly, one of the ideas that many students learned during the program was that the shape of the moon does not change noticeably during one day’s worth of apparent motion. The students observed this lack of change as they tracked with their hands and arms the moon’s apparent motion in its path across the sky. And even without the use of kinesthetic imagery to improve understanding of these patterns, the students
were engaged in processing the visual imagery of these topics (Clark & Paivio, 1991; Paivio, 1986). These visual representations were then recalled when prompted in the interview setting after the planetarium program.

As was found with the students interviewed in Study A, many children had non-normative ideas about the length of time it takes for the shape of the moon to appear to change. About half of the students thought that we could see this apparent change during one night. After the planetarium program, half of those students had improved, giving an accurate description of how long it would take to observe the phase of the moon to change. The program did not focus on teaching the students that it takes a full month to complete one cycle; rather it helped them recognize that the change is a slow process.

While the majority of students knew that the moon can be seen during the day, the majority of those who said it could not improved, leaving only 3 of the 63 students still believing that the moon is never visible during the day. There was also a large improvement seen in the students’ understanding of what happens to the stars during the daytime. Over three-fourths of the students responded accurately after the program where as slightly more than half did before.

One might have expected that students who came to the planetarium with non-normative ideas would be less likely to improve their understanding than students who were partially accurate already. Students are more likely to learn new ideas that are already aligned with their current understanding of that subject and fit into their prior knowledge (Bransford, Brown, & Cocking, 1999). In this study, I found no correlation between the students’ prior knowledge and whether or not they improved. Students who had non-normative ideas about apparent celestial motion were no less likely to improve
than students who began as partially accurate. It is not so surprising that the students who were counted as partially accurate improved as they, given that for most categories this meant an alteration to a previously held description of motion. But for the non-normative students, improvement meant a more extreme change to their understanding. This could have included learning that the sun or moon’s motion is continuous and across the sky, rather than straight up and down, or that the stars have a pattern of motion during the night rather than staying in one spot.

On possible reason to explain why the planetarium program appears to have been equally successful for children with non-normative as well as partially accurate ideas requires looking at exactly what was changing between the various levels of understanding. In many topics, improving from partially accurate to accurate understanding involved learning a different idea than moving from non-normative to partially accurate. For example, a child that improved from the idea that the stars do not move (non-normative) to being unable to describe the motion of the stars but knowing that they move (partially accurate) has learned a different concept than the student that starts with that same partially accurate idea and improves to an accurate demonstration of the apparent motion of the stars. Similarly, the difference between a partially accurate description of the sun and moon’s paths and the accurate description was, in most cases, the location the students showed for the sun or moon’s highest altitude. Students who improved learned that the sun and moon do not pass directly overhead from our latitude. Children who improved from non-normative ideas learned that the sun and moon’s paths are smooth and cross the sky. These results suggest that the planetarium program was equally successful in teaching both of these concepts separately.
Research question 3

Finally, the third research question addressed whether or not students had improved on related topics that relate to apparent celestial motion and were assessed during the interviews but not covered as part of the main instruction during the planetarium program. These dealt with the topics of where the sun and moon are when we cannot see them. The accurate answer to these topics involves describing the earth as facing away from the sun or the moon. The planetarium program focused on describing the apparent motion of the objects when they are visible and not what happens to these objects when we cannot see them. Thus it is not surprising that there was no improvement in the students’ understanding. These results do not suggest that students at this age are incapable of learning about the actual motion of the sun, earth and moon, or the shape of the earth since these are not topics the planetarium program was designed to address. There was no significant increase in the number of students who improved their understanding of the location of the sun and moon when they are not in the sky. This is not unexpected because students only observed the sun and moon to set below the horizon during the program. The program did not focus either on eliciting the students’ prior knowledge on this subject or proposing the scientific description.

Further discussion of the implications for instruction and the proposed learning progression for these topics will be discussed in Chapter 6.
This dissertation investigated children’s understanding of the apparent motion of the sun, moon and stars by conducting two related studies. The goal of the first study was to characterize students’ understanding of apparent celestial motion by topic and across grade levels. I will describe in this chapter how students’ understanding of apparent celestial motion compares to the astronomy goals for early elementary school in the National Science Education Standards (NSES) and Benchmarks for Science Literacy (Benchmarks) and how it can be used to create a learning progression for apparent celestial motion. The goal of the second study was to assess the use of instruction in a planetarium program to improve students’ understanding of these topics. Implications of these results on the learning progression will be discussed. Finally, I will also use conceptual change theory to interpret the results and discuss future directions for research in this area.

Beyond Previous Research on Children’s Knowledge of Astronomy

The results of Study A go beyond what has been found in previous studies of what children know about astronomy by focusing on apparent celestial motion rather than the explanations for astronomical phenomena. These results were made possible by the use of the mini-dome interview setting. This interview method also made it possible to
describe in detail children’s beliefs about the patterns of apparent celestial motion. In all areas of apparent celestial motion, included as topics recommended by the *NSES* and *Benchmarks*, many of the students at each grade level held non-normative beliefs about the concepts examined, though there was improvement at each grade level compared to the previous level on many topics. However, the eighth grade students continued to hold many of the same non-normative ideas as the younger students about numerous areas of the apparent motion of the sun, moon and stars. There was no significant improvement found in the eighth grade students compared to the third grade students in their understanding of the sun’s highest altitude, the change in sun’s altitude and path length across seasons, the path of the moon, and the apparent motion of the stars. The mini-dome environment used in the interview expands what can be learned about children’s ideas about apparent celestial motion beyond previous techniques: verbal questions, the use of spherical models of the objects, and drawings. It allows the students to recreate the motions that they can imagine observing in the sky. Children who have not learned about celestial motion are likely to have a limited vocabulary to use to describe their ideas. The use of the flashlight to represent the sun, moon, and stars can free students from just describing their ideas with words. It also aids in communication between the interviewer and the interviewee by allowing concepts such as continuity of motion, directionality, and altitude to be expressed by the student without the necessity of translating those concepts from verbal or 2-D representations.

Previous studies on children’s understanding of celestial motion were limited by the methods used to assess children’s ideas. This dissertation describes the first attempt at using a new method of uncovering children’s ideas about astronomy. This may
account for differences found in the children interviewed for this study and the results of Sharp’s study that also addressed apparent motion (1996). Sharp found that far fewer 10- and 11-year old children (year 6 in England) were able to describe the sun or moon’s apparent motion than the 8- and 9-year old children (third grade) in my study. His study had the children using drawings or gestures, along with verbal responses, to explain their ideas. The mini-dome environment of my study may have provided scaffolding for students who otherwise would not have had the tools to express their ideas.

Mant and Summers (1993) also used an interactive environment to assess elementary teachers’ knowledge of apparent celestial motion. Their subjects used a model that represented a person on a mountain looking around at his or her horizon. Although this allowed the researchers to ask questions about the earth based perspective, it did not provide the subjects with the same clear setting on which to demonstrate their ideas as was available with the mini-dome setting. I compared the results of their study to the ideas expressed by the eighth grade students in my study. The teachers appeared to be more knowledgeable about the changing path of the sun and the sun’s altitude, compared to the eighth grade students. Some of the difference may be explained by the teachers’ additional learning opportunities in astronomy, compared to the middle school students. However, Mant and Summers also reported that many of the teachers were unable to describe the path of the moon where as all of my students were able to accomplish this task. Rather than a difference in knowledge, this may be explained by the method used to assess the subjects’ knowledge. The eighth grade students were provided a medium in which to express their ideas that supported their limited knowledge by providing representations of the moon and the sky to manipulate. Without this
representation, the teachers may not have had the ability or confidence to express their ideas in the same manner as the eighth grade students.

Many studies on middle school, high school and adult populations’ understanding of astronomy have been conducted using surveys (Berendsen, 2005; Brunsell & Marcks, 2005; Deming, 2002; Finegold & Pundak, 1990; Lightman & Sadler, 1993; Treagust & Smith, 1989; Trumper, 2001a, 2001b, 2001c). Studies that use surveys to collect information on the frequency of alternative ideas among populations of students are only able to include alternative ideas that have previously been documented. They are also limited in their usefulness because early elementary students lack the reading comprehension abilities needed to take the same tests that one would use with older students. The use of the mini-dome, while a more time consuming method of assessment than survey methods, has now been shown to be useful with children as young as 6-years-old. It also provides the students greater freedom by allowing them to express the full range of their ideas about apparent celestial motion rather than limiting their choices.

By giving the students the freedom to express their ideas about the apparent motion of the sun, moon and stars in an environment that scaffolds their ability to describe their ideas I was able to uncover common alternative ideas that had not been previously described among children of any age. Uncovering these concepts may help the future development of instruction on apparent celestial motion by allowing us to create opportunities for students to make observations that will contradict those alternative ideas.
A Learning Progression for Apparent Celestial Motion

Introduction to learning progressions

The main purpose of the research conducted for the first part of this dissertation was to examine children’s understanding of celestial motion in ways that can be used to improve future instruction on these topics, consider the age-appropriateness of the national standards, and potentially improve assessments. Building on the topics of astronomy recommended by the National Science Education Standards (NSE; NRC, 1996) and the Benchmarks for Science Literacy (Benchmarks; AAAS, 1993), I have synthesized the results of my interviews and other relevant studies together with a conceptual analysis of the topics of apparent celestial motion to create a learning progression. According to Smith, Wiser, Anderson and Krajcik, learning progressions “describe successively more sophisticated ways of reasoning within a content domain” (2006, p. 3) and can be used to suggest how students may build upon their knowledge towards an expert understanding. It is important to note that moving along a learning progression is not inevitable. Rather the learning progression is a possible description of how students may progress with good instruction. Development of the learning progression was organized around the “big ideas” of celestial motion. Big ideas refer to central concepts that pull together coherent aspects of a domain. They can be introduced in their simplest form at an early age and “progressively refined, elaborated, and extended throughout schooling” (Smith et al., 2006, p. 5).

Even though this proposed learning progression for apparent celestial motion builds on existing research on children’s thinking, it is still only a possible description of how a learner may move through the successively more complex ways of thinking about
these concepts (Smith et al., 2006). Not all students will move through this progression in the same order, nor will they all achieve the scientific understanding. The results of my study suggest that many students will not be able to fully and accurately describe the big ideas in apparent celestial motion by middle school, though the question remains as to middle students’ capabilities with targeted instruction on these topics. There remain considerable gaps in our understanding of how children actually progress in their understanding of apparent celestial motion, especially in terms of the effect of instruction on these topics. Therefore, due to the lack of longitudinal studies of how children’s ideas change over time when exposed to good instructional materials and methods, this learning progression is inferential. And because there is no research examining the connection between the children’s knowledge of the central issues of apparent celestial motion and the actual motion that causes what they observe we cannot yet describe with evidence how the learning progression for apparent motion maps onto a progression for the understanding of actual celestial motion.

**Big ideas in apparent celestial motion**

The *NSES* and *Benchmarks* recommend that in elementary school, children should be learning about the patterns of motion of the sun, moon and stars. I have reorganized the statements in these documents within two “big ideas” that tie together similar observational patterns. The first big idea, the sun, moon, and stars all appear to move slowly across the sky with a regular pattern of motion, can be broken into separate strands for the sun, the moon and the stars. Each of these three strands will be elaborated in this section, to describe the ideas that are necessary to reach a full understanding of these patterns of motion and how children may build on initial observations to support
more complex ideas. The second big idea in apparent celestial motion describes the
apparent change in the appearance of the moon over the course of a month. These two
big ideas are based on the observable features of the patterns of motion as opposed to the
invisible features such as the rotation of the earth or the orbit of the moon.

However, despite being “observable” in nature these concepts remain challenging
to students. The patterns of motion take place over many hours, days and even months.
Recognizing the patterns of motion requires the ability to recall the location of celestial
objects at a previous time and relate that location to the object’s current position. These
changes occur in the sky and thus require that the observer be aware of the objects in the
sky and capable of making those observations, which may be limited by location or
weather. The fact that many or these changes are occurring at night while children sleep
reduces the likelihood that the necessary observations will be made. Because of these
challenges, students are likely to require instruction designed to help them make the
connections between observations that will allow them to understand the patterns of
motion.

The first big idea can be separated into the concepts relating to the apparent
motion of the sun, the moon and the stars separately. Although all of this motion can be
explained at its simplest form by the rotation of the earth on its axis, the patterns of
motion change because of other motions: the orbit of the earth around the sun, the tilt of
the earth on its axis, and the orbit of the moon. Because of the significant differences in
the overall patterns of motion of the sun, moon and stars, I will describe each as a
separate strand on the learning progression:
1. The sun’s path is a smooth arc across the sky that slowly changes in length and altitude across the seasons.

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

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

The second big idea of apparent celestial motion describes how the moon’s appearance changes over the course of a month. This motion is closely tied to the apparent change in the moon’s rising and setting times but initially students are likely to develop these concepts separately. This second big idea is not part of the moon strand of the first big idea because the phases of the moon do not depend on the apparent motion caused by the earth’s rotation.

In the following sections I will describe how children may move from initial observations about the world to successively more complex ideas. These concepts are arranged in progressions that include suggested grade ranges that students may be capable of learning those concepts. These progressions will be supported by the placement of these concepts in the NSES and Benchmarks, the results of my initial interviews with children and additional literature on children’s thinking and learning about astronomy.

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

**Development of the sun’s path concept: Grades K-1**

Figure 6.1 shows the suggested learning progression for the pattern of motion of the sun. The first basic element of the sun’s apparent motion held by children is that the
sun is in the sky during the day. The *Benchmarks* recommend that in kindergarten through second grade children should be learning about astronomy by making observations of the sky. Such observations could include the sun appearing low in the sky in the morning, high in the sky later in the day, and then low in the sky at the end of the day. Knowledge of these changes in the sun’s position in the sky may then help students to form the next concept in the progression: during the day the sun appears to rise up and then set. Whether or not a student believes that the sun appears to move in the sky during the day may influence how they explain the occurrence of day and night (Vosniadou & Brewer, 1994). Students who do not make these observations about the sun’s apparent change in position during the day may also not believe that the sun is “down” at night. Instead, they may explain the sun’s disappearance at night by saying that the sun is behind clouds, behind the moon, or has moved out into space (Baxter, 1989; Vosniadou & Brewer, 1994).

I found that 80% of the first grade students and 95% of the third grade students understood that the sun appears low in the morning, high during mid-day, and low at the end of the day before setting (though what happened in between those times did not always match the actual path of the sun). This suggests that early elementary students are capable of learning this concept though some first grade students may require focused instruction beyond what they may notice on their own.
Figure 6.1: Learning progression for the apparent motion of the sun

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

Grades K-1
- Sun in sky during the day and not in the sky at night.

Grade 2-3
- Sun rises/sets during the day.
- Sun’s motion is continuous.
- Sun rises/sets on opposite sides of the sky.

Grades 4-5
- Sun does not pass directly overhead daily.
- Sun is highest at noon.
- Length of sun’s path changes across seasons.
- Sun’s altitude changes across the seasons.
Development of the sun’s path concept: Grades 2-3

The results of my interviews with first and third grade students suggest that after developing the concept that the sun appears to rise and set, children learn one of two different aspects of the sun’s apparent motion: the sun’s motion appears continuous or the sun rises and sets on the opposite side of the sky. Acquiring each of these concepts requires a complex set of observations if a child is to learn this from his or her own observations without instruction. The concept that the sun rises and sets on opposite sides of the sky does not arise logically from the concept that the sun appears in the morning and disappears at night. While a child may notice that the sun appears successively higher from morning until the middle of the day and then lower at the end of the day, the observations necessary to conclude that this motion took the sun across the sky (rather than just up and down on one side of the sky) require comparing the sun’s position to fixed points along the horizon. Without instruction this may be beyond most young children’s abilities. Guidance by an expert could help students recognize this change in the sun’s location by pointing out how the sun’s position has changed with respect to familiar objects along the horizon.

It is interesting that even though a large portion of third grade students did not describe the sun as rising and setting on opposite sides of the sky, all of the third grade students demonstrated that the sun does not stop moving throughout the day\textsuperscript{12}. The \textit{Benchmarks} suggest that students master the concept that some changes are too slow to see in upper elementary education. The fact that some first grade students and all third

\textsuperscript{12} However, one third grade student appeared to have difficulty demonstrating the motion of the sun, and two others indicated that the speed of the sun’s motion changed.
grade students from my study were able to describe the sun as moving continuously throughout the day, while not exactly contradicting the Benchmarks’ recommendation, does suggest that students may be developing this ability much earlier than they suggest. However, the explanation for how students learn this concept is not obvious. It is likely that these children had learned about the rotation of the earth prior to these interviews because this is a common topic of instruction for elementary students. A portion of the third grade students used the earth’s rotation in their descriptions of the motion. Conceptualizing the apparent motion of the sun in terms of the continuous motion of the earth’s rotation may have helped the students develop this concept. However, since not all students appeared to be using the rotation of the earth in their explanations, it is unlikely that this is the major factor in the development of the concept of continuous motion of the sun.

Learning one concept (the sun moves continuously) does not seem to depend on learning the other (the sun moves from one side of the sky to the other), as can be seen in the interviews with the first and third grade students in my study. In first grade, the majority of the children did not demonstrate that the sun moves continuously across the sky though some knew that the sun rises and sets on opposite sides of the sky. The third grade students I interviewed knew that the sun’s motion does not remain unmoving at the top of the sky although a large fraction of children did not know that the sun does not rise and set on opposite sides of the sky. This may be due to a lack of experience in observing the location of where the sun rises and sets or because children are still developing their spatial orientation abilities (Roberts & Aman, 1993). I have placed
these two concepts in the learning progression in grades 2 to 3 because 70% of the third grade students demonstrated a path for the sun that crossed the sky and was continuous.

**Development of the sun’s path concept: Grades 4-5**

The concepts described up to this point are those that the middle school students had already mastered. Nearly all of the eighth grade students described the sun’s path as a smooth curve that crossed the sky and moved continuously throughout the day. The remaining concepts, which go beyond this simple description of the path of the sun, are ones that only a small percentage of the eighth grade students understood. However, because most astronomy instruction does not specifically deal with these aspects of the sun’s apparent motion it is not surprising that the students were not able to describe these topics.

While most of the eighth grade students interviewed knew that the sun is highest at noon (60% in both seasons), only 40% of third grade students understood this concept in both summer and winter. Understanding that the sun is highest in the sky at midday requires that students have a continuous model of the sun’s apparent motion so that there can be a specific time of day that the sun appears highest in the sky, as opposed to believing that the sun spends most of the day at the top of the sky (a belief held by many first grade students). Just as with other aspects of the sun’s path, learning that the sun is highest at noon requires a complex set of observations which suggests that if students learn this concept it is through school or other cultural references. Students who believe the sun is highest at some other time of day may be basing this on some of their own observations. For example, some students may find the concept that the sun is highest in
the middle of the day to contradict their experience that the daily temperature peaks in the afternoon.

Some students also believed that the sun reaches its highest point in the sky at different times in different seasons. Most of the third grade students interviewed for this study (65%) knew that the sun was highest at noon in the summer, but only 40% believed the sun was highest at noon in the winter. They may also try to reconcile differences in the length of day across seasons by believing that the sun’s highest altitude occurs different times of the day in summer compared to winter.

Instruction on the concept ‘the sun does not pass directly overhead’ could be done in concert with the notion that the sun is highest in the middle of the day. These concepts are the next logical step for students to learn after they understand that the sun’s apparent motion can be described as a smooth arc across the sky because they make modifications to that basic notion. My study, as well as previous surveys of middle school (Trumpler, 2001a) and high school students (Lightman & Sadler, 1993; Trumpler, 2001b) found that the majority of students believe that the sun passes directly overhead everyday. Aside from my study of children learning in the planetarium, the astronomy education literature does not contain any studies of children learning that the sun does not pass directly overhead. However, because this concept is accessible based on direct observations and is not an abstraction of invisible motions, it may be most appropriate as a concept to be learned in elementary school. For this reason, the concept was placed in the upper elementary section of the learning progression.

The Benchmarks fails to include the concept of the sun’s changing path over the seasons, though it is included in the K-4 section of NSES. Previous studies of children
and adults’ knowledge of the seasons, both with and without instruction, have focused on how they explain this difference in terms of the tilt of the earth not what we can observe or experience. My study of celestial motion is the first to address children’s knowledge of the apparent change of the sun’s path across the seasons. This concept is accessible to students through direct observations (though these observations must be made over a long period of time and are likely to need a high level of guidance from more expert observers). Because this concept addresses a phenomenon that is observable, these aspects of the seasons may be more appropriate for children to learn first, and at a younger age, than the more abstract aspects of the seasons such as the earth’s rotation, tilt and orbit. Students can learn that the path of the sun is changing by making observations of shadows cast by the sun at noon and by recording the rising or setting position of the sun across many weeks. Instruction on these changes across seasons may be more successful if the students already understand that the general shape of the sun’s path across the sky; for this reason the seasonal change to the sun’s path was placed in grades 4 to 5 of the learning progression.

Several studies have shown that accurately explaining the cause of the seasons is challenging for both children and adults (Atwood & Atwood, 1996; Parker & Haywood, 1998; Sadler, 1992; Trumper, 2001a; 2001b, 2001c). Salierno, Edelson, and Sherin (2005) conducted a case study with three fifth-grade students of how the knowledge of the seasons changed after participating in an in-depth investigation about the earth’s surface temperature. The instruction, which focused on the angle of the sun’s light and the tilt of the earth, helped the students achieve a partial understanding of the seasons but they retained some of their initial alternative ideas. Traditionally, the seasons are taught
by introducing the tilt of the earth without helping them understand all of the consequences. An open question remains as to whether teaching children to notice changes to the sun’s path and altitude across the seasons may help them form a more complete and accurate understanding when exposed to instruction on the tilt-explanation of the seasons.

**Big Idea 1B: The moon moves across the sky on a daily basis in a similar path to the sun, sometimes during the day and sometimes at night**

**Development of the moon’s path concept: Grades K-1**

Figure 6.2 shows the suggested learning progression for students’ understanding of the apparent motion of the moon. By first grade, students are likely to be aware of the moon and its appearance in the sky. The first step in learning about the moon’s apparent path across the sky is to believe that its location changes over time. All first grade students interviewed for Study A believed that the moon does appear to move though two students did not demonstrate that motion. The majority of the first grade students (90%) gave some indication of the rise and set concept for the moon through description or demonstration. This does suggest that by the end of first grade we can expect most students to develop this concept, and perhaps all if they are provided with instruction that describes the moon as rising and setting like the sun. Another valuable observation for instructional design is that many children believe the sun and moon exhibit the same patterns of motion. About half of the first grade students (55%) indicated the same pattern of motion for the moon as they had previously indicated for the sun (primarily non-normative paths). Instruction that emphasizes the similarities between the motion of the sun and moon may be more successful because it connects with many students’ prior knowledge and will allow them to develop understanding of these concepts.
simultaneously. This also may help students learn the apparent motion of the moon because children have more familiarity with the apparent motion of the sun.

The second concept included in the beginning of this strand is the idea that the moon visible sometimes during the day and sometimes at night. This concept provides a basis for learning that the moon rises and sets at different times at a later stage in the progression. The interviews with first grade students show that many still believe the moon can only be seen at night. However, because students can readily learn that the moon is visible during the day by having a teacher or parent point it out in the sky it seems reasonable to expect that children are capable of learning this concept by the end of first grade. Instruction on both of the concepts at this level could be combined through a few observations of the moon on the same day by pointing out that the moon appears successively higher or lower throughout the school day.
**Big Idea 1B**
The moon moves across the sky on a daily basis in a similar path to the sun, sometimes during the day and sometimes at night.

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**Grades K-1**
- The moon appears to rise and set like the sun.
- The moon is visible sometimes during the day and sometimes at night.

**Grades 2-3**
- The moon’s motion is continuous.
- The moon rises/sets on opposite sides of the sky.

**Grades 4-5**
- The moon rises/sets 50 minutes later every day.
- The moon’s apparent distance from the sun in the sky is correlated with its appearance.\(^a\)

\(^a\) This concept is part of Big idea 2.
These two concepts, the rising/setting motion of the moon and the moon’s
daytime appearance, do not seem to be linked: one concept does not lead to improved
understanding of the other. Logically, one does not require learning the other. There did
not appear to be a correlation between the type of path that first grade students described
and whether or not the students believed that the moon could be seen in the day as well as
the night.

**Development of the moon’s path concept: Grades 2-3**

Just as with the apparent motion of the sun, the next steps in the learning
progression are to learn that a) the moon’s apparent motion is continuous and b) the
moon rises and sets on the opposite sides of the sky. These concepts are not logically
linked and the interviews with third grade students suggest that children are capable of
understanding one without understanding the other. From a conceptual stand point, the
idea that the moon’s motion is continuous and from one side of the sky to other extends
the earlier concept that the moon rises and sets. It also connects to the apparent motion of
the sun because of the similarity in paths. These are the same concepts as I have
recommended students learn about the sun at the Grade 2-3 level.

The interviews with third grade students suggest that children are capable of
understanding both of these concepts by third grade. Similar to the change in knowledge
observed with the sun concepts, the majority of third grade students (85%) believed that
the moon moves continuously through the sky where as a the majority of the first grade
students (60%) believed that it remains at the top of the sky for an extended period of
time. Instruction designed to explicitly describe the smooth, continuous nature of the
moon’s motion may help all students improve to a scientific description. The majority of
third grade students (70%) also demonstrated that they believe the moon rises and sets on opposite sides of the sky. If students are guided to make observations of the changing location of the moon this may help them understand that the moon rises and sets on opposite sides of the sky like the sun. Some students may require this additional help in making the observations in order to learn this concept.

The observations needed to track the moon’s apparent motion across the sky are time consuming and complex. This makes it unlikely that the majority of students are making these types of observations in school or at home. Yet the majority of third grade students were aware that the moon rises and sets on opposite sides of the sky. As mentioned previously, many students use the same description for the sun and the moon’s motion (50% of third grade students in my study). Perhaps some students are learning the apparent motion of the sun and then applying this to their description of the moon because both are celestial objects. This also ties in with the common belief among young children that the moon and sun move opposite in the sky, with one rising as the other sets (Vosniadou & Brewer, 1994).

A portion of the students (15% of the third grade students; 35% of the eighth grade students) indicated that they believe the moon does not appear to rise and set. This increase in the number of middle school students, compared to elementary students, may be the result of instruction on the actual motion of the earth and moon that has been misinterpreted by the older students. I propose three possibilities for the genesis of this belief. First, students who learn that the moon is visible in both the day and night may conclude the moon is visible every daytime and every nighttime. This may lead them to conclude that the moon stays up in the sky all of the time. Second, when students learn
that the moon orbits around the earth, they may interpret this to mean that the moon appears to circle around in our sky. Third, some students (in particular the students who say that the moon never appears to move) may have interpreted the concept ‘the moon stays in place but the earth rotates’ to mean that the moon does not appear to move as well. Each of these possibilities suggests the need for care when teaching students about actual celestial motion to also include the consequences to apparent celestial motion. Tracking the moon’s position in the sky may help some of these students think about the moon moving across, not around, the sky. Working with models could also be successful, with appropriate care in emphasizing the period of the earth’s rotation versus the slow orbit of the moon.

**Development of the moon’s path concept: Grades 4-5**

The concepts placed at the Grades 4 and 5 level are not explicitly mentioned in either the *NSES* or the *Benchmarks*. However, both of these concepts are part of the pattern of apparent motion of the moon and are tied to the concept of the phases of the moon. The first of these concepts is that the moon rises about 50 minutes later every day. The second is that the moon’s appearance changes as it is closer and further from the sun in the sky. This second concept is also placed in the learning progression for Big Idea 2 and will be discussed in depth in that section. But it will be mentioned here because of the links between these two strands of the learning progression.

The change in the moon’s rise and set time occurs because the moon is orbiting the earth. Examining recordings of the daily rise times of the moon reveals that it rises at the same time about every 28 days, or once an orbital period. Students in grades 4 and 5 may not be ready to fully understand the concept of the moon’s orbit but they can keep
track of the rising and setting times, and with guidance discover the pattern of the moon’s apparent motion. This could be done with direct observation or aided by charts that give the moon’s rise and set time each day (such as the newspaper or an almanac).

The interviews in this dissertation did not address students’ knowledge of the pattern of the moon’s rise and set time. However, many of the eighth grade students (35%) did not believe the moon actually rises and sets and therefore do not know that there is a pattern to the rising and setting time of the moon. Given a lack of emphasis on topics of apparent motion in astronomy curriculum, these students are not likely to have had instruction on this topic. Therefore we may suppose that many of the other students are also unaware of the pattern though they may be aware of the length of time for the moon to cycle through its phases (some of the eighth grade students indicated this idea during their interview).

Students can learn the pattern of the moon’s rise and set time from an almanac or the newspaper. However, if they are observing the moon in the sky the have the potential to connect other aspects of the pattern of the moon’s apparent motion and changing appearance. Observations designed to guide students in understanding the pattern of the moon’s motion across the sky can also be used to observe the change in the moon’s rise and set time. The students may also begin to notice that the moon’s position in the sky is closer to and farther from the sun in the sky throughout the month. If students are guided to connect this pattern with the appearance of the moon, students may be more successful at learning the explanation of the phases of the moon once they have also learned about orbits and the properties of light.
Big Idea 1C: The pattern of stars remains the same but appear to move across the sky nightly. The stars visible after sunset changes slowly across the seasons.

The third aspect of Big Idea 1 describes the apparent motion of the stars during the night and how the pattern of stars we see changes across the seasons. The learning progression for this topic is shown in Figure 6.3. Analysis of the apparent motion of the stars concept, both from a conceptual standpoint and based on research on children’s understanding, suggests that some of the more sophisticated aspects of this area are appropriate for middle school grades. Therefore, unlike the other four strands discussed for celestial motion, this strand of the learning progression extends to Grades 6 to 8.

To understand that the stars continue to rise and set throughout the night requires the learner to believe that there is a continuous “supply” of stars that will allow new stars to appear over the eastern horizon as old stars to disappear as they set in the west. The actual reason this motion occurs is because the earth is surrounded by stars in every direction. The stars are at such a great distance that they do not appear to be moving with respect to each other, forming fixed patterns in the sky that we call constellations. As the earth rotates, the stars appear to rise and set throughout the night; this pattern continues throughout the daytime but we are unable to observe this because the sky is too bright. The full description of the stars’ location and apparent motion includes understanding the shape of the earth and its actual motion. Previous research suggests that even with good instruction children do not develop the full concept of the earth until fourth or fifth grade (Agan & Sneider, 2004).
Figure 6.3: Learning progression for the apparent motion of the stars

**Big Idea 1C**
The pattern of stars remains the same but appear to move across the sky nightly. The stars we can see after sunset changes slowly across the seasons.

**Grades K-1**
The stars appear in the sky at night but not during the day. The stars have different brightness.

**Grades 2-3**
The pattern of stars stays the same.

**Grades 4-5**
The stars appear to move across the sky nightly.

**Grades 6-8**
Many of the stars appear to rise and set along the same pattern of motion as the sun and moon.

The stars visible after sunset change slowly across the seasons.
Development of the motion of the stars concept: Grades K-1

Because of the challenges presented by the apparent motion of the stars, children may benefit by first focusing on simple aspects of the stars’ location and appearance to establish a foundation for learning the full patterns of motion when they are older. Children will initially notice that we can see the stars at night but not the day. However, understanding the pattern of motion of the stars becomes more complex beyond this simple observation. Children are likely to have seen the stars in the sky at night by first grade, if briefly. A few of the children in this study said that there are “too many” stars for us to tell if there is any change to the stars at night. The myriad of stars is likely to be too overwhelming for children at this age (as well as many adults) to discern patterns among the stars. However it may be helpful to begin to point out that some stars are brighter and some stars are fainter.

Development of the motion of the stars concept: Grades 2-3

I have placed the concept that the pattern of stars in the sky does not change at the Grades 2-3 level. By this I mean that the stars do not change their position with respect to each other. Understanding this concept could include beginning to learn about the constellations, though memorizing these patterns is not necessary (AAAS, 1993). This will be a useful concept to establish before attempting to address the full extent of the pattern of apparent stellar motion. However, Grades 2 and 3 may be too early for some students to learn this concept. The Benchmarks place the concept in Grades 3-5. This dissertation did not analyze this concept; therefore further study is needed to understand children’s abilities in this area.
Development of the motion of the stars concept: Grades 4-5

The results of this study suggest that without well-designed instruction on these topics many children will not have an accurate understanding of the next two concepts of the learning progression by the end of elementary school: the stars are still in the sky during the day and the stars appear to move slowly across the sky. Only half (45%) of the third grade students understood the concept that the stars are still in the sky during the day, but not visible because the sky is too bright. Vosniadou and Brewer’s study (1994) also found that 45% of third grade students and 60% of fifth grade students knew there were stars in the sky during the day. The concept shows improvement with older students: 85% of the eighth grade students in my study were aware of the stars’ daytime location. In a study of instruction that focuses on the earth’s rotation, Diakidoy and Kendeou (2001) found that 31% of fifth grade students had difficulty inferring that the stars are still in the sky during the day (though their study did not take into account the children’s mental models of the stars’ location surrounding the earth).

Instruction on this concept may be difficult because there is no easy way to observe that the stars are still in the sky during the day. One way to overcome this obstacle is to focus on the location of the stars. As students learn about the shape of the earth, they can also learn that the earth is surrounded in all directions by stars (thus we face stars during the day and night). Students may also benefit from instruction that explains how the stars could still be in the sky even though they are not visible, such as demonstrations that show fainter lights becoming harder to see when a bright light is turned on. Students could also observe what happens to the stars as the sun is just about
to rise, though this would likely require the cooperation of parents in guiding the observations.

The second part of the learning progression at Grades 4-5 is the concept that the stars appear to move. At this level, I am only suggesting that students learn that the stars’ location appears to change slowly not the full description of the stars’ pattern of motion. Evidences from studies of elementary, middle school, and adults suggest that students are not learning this pattern of motion and that many are not aware that the stars appear to move at all. Only half of the third grade students in my study believed that the stars appear to move (though another 20% believe the stars only move at the end of the night). Even less (14%) of the 10- and 11-year old students in Sharp’s (1996) study believed that the stars appear to move (though the difference in interview techniques may explain this difference in the percentages). There was no difference in the number of students in eighth grade who believe the stars appear to move compared to the third grade (though slightly more were able to describe this motion). Among the elementary school teachers interviewed by Mant and Summers (1993), all were aware of the apparent motion of the stars but only 20% were able to describe that motion.

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

In the learning progression described in Figure 6.3 I have shown the concept that the stars appear to move to follow the concept that the stars are in the sky during the daytime. The first progression makes sense from an instructional and logical standpoint based on a full understanding of the concept. However, because it is possible to imagine the stars moving without believing they are in the sky during the day, I have also suggested by the use of a dashed arrow, that some students may progress to the concept that the stars appear to move without understanding the other idea.

Instruction that helps students understand that the stars appear to move will be challenging. Aside from the study I have conducted on planetarium instruction there has been little work to explore children’s abilities to improve with good instruction. Making observations that the stars appear to move requires first, that the student go out and make multiple observations over an hour or so at night and second, that the student has the ability to recognize a single star in order to track its position. Without the aid of a planetarium to demonstrate these motions on a faster time scale, instruction on the apparent motion of stars may require that students understand the reason why the stars appear to move: the rotation of the earth. This is certainly an area that will require future research to establish the most successful course of instruction on these topics.

Despite the evidence that many children have alternative ideas about the stars’ location and motion in elementary school, I have placed these concepts as goals of the learning progression in upper elementary school. These concepts are prerequisite to understanding the continuous apparent motion of the stars. Because at least half of the
students interviewed in upper elementary grades understood that the stars appear to move and are still in the sky during the day, additional students may also be able to understand these concepts with good instruction that considers the alternative ways students understand these topics.

**Development of the motion of the stars concept: Grades 6-8**

The last two pieces of the stars’ apparent motion are a) the full description of the stars’ rising and setting throughout the night and b) the change in the stars we see over the seasons. The first concept builds on the goals of previous stages of the learning progression but it also relates to the students’ understanding of the patterns of motion of the sun and moon. Once students have mastered the rising and setting patterns of the sun and moon, they may find it easier to describe the stars as exhibiting a similar pattern of motion. But developing this knowledge will certainly require instruction that helps the students imagine the nature of this pattern of motion. The present study, as well as Mant and Summers’ (1993) study of elementary teachers, demonstrates that middle school students and adults are likely to be unable to describe the stars’ apparent motion without this instruction.

My study also shows that instruction will need to emphasize that we see different stars throughout the night because of the rising and setting motion of the stars. Only 15% of the eighth grade students in my study were aware that the stars we see after sunset are not the same as the stars we see before sunrise because of the rising and setting motion. The majority (80%) believed that we see the same stars all night long.

The final piece aspect of the apparent motion of the stars is the concept that we see different stars after sunset during different seasons. This is the result of the orbit of
the earth around the sun which causes any given star to rise 4 minutes earlier every night. It takes slightly less time for the earth to turn back to that star because the earth has moved part of the way around the sun in its orbit. Another way of imagining this concept is to consider it from a seasonal perspective; the night side of earth is facing in one direction in the summer and facing in the opposite direction in winter after the earth has completed one-half of its yearly orbit.

By middle school, the NSES and Benchmarks recommend that students learn about the earth’s orbit around the sun. However, at present, there exists no relevant research to report on children relating our observations of different stars across the seasons and the orbit of the earth. This was not a topic that I covered in the interviews for this study. This area will require future work to adequately place it along a learning progression in relation to both apparent and actual celestial motion.

Big Idea 2: The appearance of the moon changes slowly over a period of 28 days

The shape of the moon appears to change slowly over the course of 28 days because as the moon orbits the earth we see first more of the side facing the sun and then less of the illuminated side. However, children in elementary school are likely to have difficulty understanding and using the explanation for the apparent change to the moon’s appearance (Kavanagh, Agan, & Sneider, 2005; Stahly, Krockover, & Shepardson, 1999). The purpose of this strand of the learning progression is to suggest how children may build upon early observations to a complete understanding of the observational aspects of this change. If children have this full descriptive understanding of the phases of the moon they may be more successful in learning the explanations for the pattern of
change, though this will require further research to establish. Figure 6.4 shows the suggested learning progression for the moon’s appearance.

**Development of the change in the moon’s appearance concept: Grades K-1**

The basic concept this progression builds upon is that the moon does not always look the same in the sky. The majority of first grade students (75%) were able to make at least two reasonably accurate drawings of the shape of the moon showing that they were aware of the change in the moon’s appearance. This concept can be taught using pictures of the moon and though actual observations may be a more powerful way of demonstrating that the moon’s appearance changes. This may be done in conjunction with aspects of the learning progression for the apparent motion of the moon (Figure 6.2), establishing that the moon can be seen in both the night and the daytime.

**Development of the change in the moon’s appearance concept: Grades 2-3**

The next two steps in the learning progression build one upon the other. The first idea is that the moon’s appearance changes so slowly that from day to day the moon appears very much the same but over a few days significant change may be observed. The second idea is that the moon goes through an entire cycle of phases in 28 days. Both of these concepts can be observed by students, if they are guided to do so. Students can make drawings of the moon at several times through the day or evening. They can then compare this to observations on several days through out the month. These observations can also be used to help establish the apparent motion of the moon.
Big Idea 2
The appearance of the moon changes slowly over a period of 28 days.

Grades K-1
The moon’s appearance changes going through specific shapes.

Grades 2-3
The appearance of the moon changes very slowly, looking a little different every day.

Grades 4-5
The moon goes through a full cycle of phases in about 28 days.

The moon’s apparent distance from the sun in the sky is correlated with its appearance.
Only half of the third grade students (50%) gave an accurate answer to the length of time it would take to observe a significant change to the moon’s appearance. Most of the students with alternative ideas believed that this change could occur in minutes or hours. However, because students can make their own observations of the moon to determine the period of change, it seems reasonable to suggest it is attainable by most third grade students. Future research that investigates the use of children’s own observations of the moon may help us more confidently place these concepts on the learning progression.

**Development of the change in the moon’s appearance concept: Grades 4-5**

The final concept of this learning progression begins to link the moon’s position in the sky relative to the sun with its phase. When the moon appears close to the sun in the sky, we see a thin crescent phase. Over the next 2 weeks it appears farther and farther from the sun in the sky until it is opposite from the sun and we see a full moon. The pattern reverses as the moon then moves closer and closer to the sun and the illuminated portion shrinks. If students have observed this phenomenon, and can visualize it, they may find modeling the phases with representations of the sun, moon and earth less challenging.

At this time, there is no relevant literature on children or adults learning this concept. This study has shown that even a large portion of middle school students do not have an accurate understanding of the moon’s path across the sky or the time it takes for the phases of the moon to change. This suggests very few students will notice this pattern on their own. It is also likely to go beyond what most instruction focuses on currently.
Summary

In this section I have proposed a learning progression for the apparent motion of the sun, moon and stars. Because so little research exists on children’s ideas about the patterns of celestial motion and none on instruction designed to teach these topics I have based this progression primarily on my own study of children’s knowledge and the logical progression of concepts in this field. In the next section I will discuss the implications for the learning progression of the significant improvement shown by first and second grade students in the planetarium study described in Chapter 5.

Children Learning About Apparent Celestial Motion

The goal of Study B was to examine whether early elementary students will demonstrate improved understanding of apparent celestial motion after participating in a planetarium program with instruction emphasizing kinesthetic learning techniques. The first and second grade students in the study showed significant improvement in all areas of apparent celestial motion that were included in the planetarium program, those covered using kinesthetic learning techniques and those that were not. This demonstrates one of the most important results of this study: students as young as first and second grade are capable of learning the topics suggested by the NSES and Benchmarks. The study described here was the first to investigate whether or not students are capable of learning and describing these patterns of apparent celestial motion. While not all students improved, the majority of students were coded as accurate for all but one of the topics from the planetarium program13. This suggests that a planetarium program using

13 Only 43% of the students were able to answer accurately about the idea that different stars are seen throughout the night.
kinesthetic learning techniques to engage the students is a successful method of improving student understanding of apparent celestial motion. Further, children are able to learn these patterns of apparent celestial motion without instruction that attempts to improve the students’ understanding of the underlying cause of this motion.

Not only was there significant improvement in all topics taught in the planetarium program, but the first and second grade students showed a more accurate understanding of celestial motion in their post-instruction interviews than the third and eighth grade students interviewed for Study A in all areas. For example, one of the concepts that appeared to be show the least improvement in the planetarium was the idea that we see different stars throughout the night because they rise and set. Only 43% of the students gave accurate answers to this question after the planetarium program. However, only 5% of the third grade students and 15% of the eighth grade students from Study A gave an accurate response to this question. Similarly, 60% of the first and second grade students were able to accurately compare the path of the sun between summer and winter after receiving instruction in the planetarium, though none of the third and eighth grade students accurately made this comparison.

**Implications for the learning progression**

The suggested learning progression described above did not include the results of Study B as support for the decisions to place concepts at various age levels. Comparing the results of Study B to the learning progression shows that most children are capable of learning these concepts at the ages suggested or at younger age levels.

Beginning with Big Idea 1A (apparent motion of the sun), after the planetarium program most students demonstrated accurate or partially accurate understanding of the
Grades 2-3 concept: the sun’s path crosses the sky, and the Grades 4-5 concept: the sun does not pass directly overhead daily. While not all students learned these concepts, the minority that did not may still learn these concepts at the grade levels recommended in the learning progression, or with additional instruction beyond a single planetarium program. There was also significant improvement in students' understanding of the change in the sun’s path across the seasons, though this was one of the areas that the most students retained non-normative ideas. This may be because these students had not reached all of the prerequisite ideas along the learning progression. It also supports placing these concepts further along the learning progress than the earlier concepts demonstrated accurately by a higher portion of the students after planetarium instruction.

The significant improvement in the first and second grade students’ understanding of the path of the moon also suggests that students are capable of learning this aspect of Big Idea 1B by third grade. Most of the students showed an accurate or partially accurate path for the moon, demonstrating that they knew that the moon rises and sets on opposite sides of the sky. Nearly all of the students knew that the moon was visible both day and night after the planetarium program as well. The last link on strand, which describes how the moon’s rise and set times shift later each day, was not assessed after the planetarium program.

The results of the planetarium program suggest that some students may be capable of understanding and describing the apparent motion of the stars, Big Idea 1C, earlier than I have recommended in the learning progression that was based on interviews with students who had not received planetarium instruction. In the learning progression, this concept was placed in the Grades 4-5 level. After the planetarium program, 61% of the
first and second grade students were capable of demonstrating the apparent motion of the stars (though this did not always including rising and setting). With additional instruction these students or perhaps older students may show greater improvement. Or perhaps given the same instruction, a larger portion of older students will improve to an accurate understanding. This is an area that will require additional research that combines instruction in and out of the planetarium and at different grade levels.

There was less improvement on the concept that we see different stars throughout the night (a result of the rising and setting of stars, placed at the Grades 6-8 level of the progression). Only 43% of the students described this accurately. However, this still leaves open the possibility that upper elementary students may show greater improvement or that additional instruction will be necessary to improve understanding of this concept area.

The planetarium program was highly successful in improving students’ knowledge that the stars are still in the sky during the day. After the planetarium program, 79% of the students were accurate compared to only 54% before the program. This suggests that students in early elementary school are capable of learning this concept if provided with convincing instruction and representations. The learning progression places the stars’ daytime location at the Grades 4-5 level because previous studies have shown that many children still do not understand this concept by late elementary school. However, based on the planetarium results, it may be appropriate to place this at the grades 2-3 level.

The results of the planetarium program support placing the concept that the moon’s appearance changes very slowly (Big Idea 2) at the Grade 2-3 level. The number
of students who accurately described the length of time for the change in the moon’s appearance improved from 37% before the program to 66% after the program. With the addition of instruction outside of the planetarium program, this percentage may improve.

**Kinesthetic learning techniques and improvement in the planetarium**

In the analysis described in Chapter 5, I examined separately the topics that were covered using kinesthetic learning techniques (KLTs) and those that were not. The topics covered using KLTs were those that lent themselves to having the students mimic motion with their arms or point to positions around the dome in order to emphasize differences in location. These topics were the apparent motion of the sun (including its path and altitude), the change in the sun’s path from summer to winter, the apparent motion of the moon, the apparent motion of the stars and the change in the stars throughout the night. The topic of the cause of daytime was also included in this list because the students were following the motion of the sun as it rose in the morning. Topics that were part of the planetarium program but not directly taught using KLTs included the length of time for a change in the moon’s appearance, the disappearance of the stars during the day, and the appearance of the moon during the day.

This is the first study to investigate instruction designed to improve students’ understanding of apparent celestial motion. There are also few studies involving kinesthetic motion in instruction with which to compare the success of these techniques. I have proposed that one way the KLTs helped the students learn was by providing the students with an additional mode to processing beyond the verbal or visual imagery. Dual coding theory suggests that there are separate cognitive processing systems for verbal and non-verbal experiences (Clark & Paivio, 1991; Paivio, 1986). Previous
studies have also suggested that students show improvement via the dual coding of kinesthetic and visual or auditory stimuli in studies about length, balance, and speed (Druyan, 1997) and in nanoscale science using haptic feedback with computer visualizations (Jones, Minogue, Tretter, Nigishi, & Taylor, 2006). The kinesthetic learning techniques in my study were designed to match the motions that the students were observing in the planetarium. In this way, the students were forming kinesthetic imagery, stored in their memories in a similar fashion to the visual imagery also processed during the planetarium program. By working through these concepts in both the kinesthetic and visual sense together, they can be accessed simultaneously in coordination with the verbal cues at a later time.

Beyond the multiple ways of processing the information, the students were learning a new way of demonstrating these motions. When the students were re-interviewed, following planetarium instruction, they had a new way of describing the motions of the sun, moon and stars that they could then reproduce in the mini-dome interview environment. Perhaps this is a limitation of this study in that the students were interviewed in a context that was not far removed from the setting in which they learned the concepts. But it does reveal that the students learned how to perform kinesthetically in contexts similar to the planetarium, a representation designed to imitate the actual sky.

The kinesthetic learning techniques may have helped the students learn in other ways as well. First, the students were actively engaged throughout the planetarium program rather than just passive observers. The students were often asked to demonstrate their prior knowledge of apparent celestial motion in order to activate the appropriate areas of their memory of astronomy topics. They then had the immediate opportunity to
compare their prior ideas with the demonstration of the accurate model of motion while they followed this motion with their arms and bodies. Second, the planetarium environment focused the students on the topics by explicitly demonstrating the concepts in a visually rich fashion. The students experienced a simulation of the actual patterns of motion across in the day and night sky that went beyond what they could ordinarily observe because we were not limited by time, weather, or the brightness of celestial objects. Finally, the KLTs may have helped the students learn because I was able to guide the students towards the aspects of the patterns of motion I wanted them to observe. This minimized distractions that could have prevented students from noticing key features such as the direction of the sun, moon and stars’ motion or that the sun and moon follow the same path across the sky.

These three additional ways that kinesthetic learning techniques helped students learn may also explain why the students demonstrated significant improvement in additional areas covered in the planetarium program that were not taught using the students’ own motions. The kinesthetic learning techniques helped to focus the students during the planetarium program and keep them engaged. This may have increased the amount of processing in the verbal and visual modes for these additional topics. For example, many of the students improved their knowledge of how long it takes for the appearance of the moon to change. One of the alternative ideas expressed among many of the students before the planetarium program was that the moon’s appearance changes from one phase to another during a single night. The students tracked the motion of the moon as it moved across the sky and at the same time observed that its appearance did
not change significantly. Thus it was the combination of these experiences that improved students retention of the concepts.

This study has also demonstrated a specific area of astronomy that the planetarium is ideally suited as an environment for instruction. While a few studies in the past have shown that students learned from participatory planetarium programs (Bishop, 1980; Mallon & Bruce, 1980), none of these studies was able to demonstrate the same significant improvement across multiple topics from a single planetarium program. This study further validates the claims of planetarians Friedman, Schatz, and Sneider (1976) who proposed that planetarium programs should be participatory in nature. This study supports the use of this type of program in the planetarium to teach apparent celestial motion.

Revisiting conceptual change theory

In Chapter 2, I discussed some of the variety in how conceptual change theory is discussed in the literature. In this section I will discuss how those theories can help us understand the nature of the changes in these students’ understanding of apparent celestial motion. In learning about the patterns of apparent celestial motion, the students’ lack of extensive observational experience may have both hindered and helped the students learn the accurate descriptions. With a limited amount of experience, the students may not have held strong beliefs about their alternative ideas, as can be a problem for many areas of physics, allowing for more freedom to accept new ideas that do not conflict with previously held assumptions. On the other hand, the students’ inexperience with observing the celestial objects and their motion may have limited their ability to learn some concepts such as the changing path of the sun across the seasons or
the idea that we see different stars throughout the night. Without prior experience observing or learning about the prerequisite ideas to these concepts, the students may not have had a foundation to build on.

The concept that we see different stars throughout the night as the result of the rising and setting of stars was one that many students continued to hold non-normative beliefs about, even after the planetarium program. Many students still believed that we do not see different stars throughout the night. Why was this more difficult to learn than the other topics? One of the primary reasons that this may be difficult is that students have little prior knowledge of the stars and their apparent motion. Perhaps changing one’s understanding of the apparent motion of the stars requires a more fundamental shift in understanding of the nature of the stars as celestial objects and the complexity of a “system” of stars than the motion of the sun or moon. And mastering this concept may also require several prerequisite concepts about the location of the stars and their fixed pattern in the sky. On top of this, the mental imagery and related verbal descriptions may not have formed the connections necessary for students to manipulate these ideas and answer questions about the pattern of motion.

During the planetarium program the students observed that the stars have a similar pattern of rising and setting as the sun and moon and that we see different stars throughout the night. Students who do not believe we see different stars throughout the night may have difficulty changing to the scientific concept. In a highly systematic knowledge structure, such as described by Vosniadou’s theory (Vosniadou, 2002; Vosniadou & Brewer, 1994), this would require that many ideas change in tandem as the concepts in question are highly integrated with other related concepts. On the other hand,
if students’ understanding of the stars and their pattern of motion is better described as a loosely held together collection of ideas, as described in diSessa’s Knowledge in Pieces theory (diSessa, 1996), perhaps the difficulty lies more in the students’ lack of prior knowledge. The children do not connect the idea of rising and setting with the stars – a concept made more challenging if the students do not understand that the motion of the stars is uniform and continuous and that the pattern of stars is fixed. Making the new connections among ideas may still be to challenging for some students with such limited experience or with alternative beliefs about the nature of the stars and the causes of apparent celestial motion.

A large fraction of the students interviewed changed from a partially accurate description to an accurate description of the patterns of celestial motion. In many cases this change in the description may be more accurately described as an assimilation of new ideas than a radical restructuring of students’ mental models. This is because the students with a partially accurate belief have the general sense of the direction and shape of the object’s apparent motion. To change to an accurate description may involve an alteration to the path they described rather than a new description. For example, to change from the belief that the sun passes directly overhead every day to the belief that it never passes directly overhead does not necessarily require a shift in other areas of understanding. This change does not alter the nature of the motion, just where in the sky we would see it in the middle of the day.

This study did not attempt to uncover and describe the students’ reasoning for apparent celestial motion. The planetarium program was not designed to improve their understanding of why the patterns of motion appear as they do, just that they exhibit these
patterns of motion – as is recommended by the NSES and *Benchmarks*. The analysis showed that there was no significant change in how the students described the location of the moon when it is not visible and the location of the sun at night – two concepts that are closely tied to their underlying models of the actual motion. The lack of change in these topics suggests that the students’ ideas about apparent celestial motion changed without altering their understanding of the mechanism for that motion. Thus students could have improved in their descriptions of apparent celestial motion while retaining the same non-normative reasoning (such as the sun orbiting the earth to cause the patterns of motion we observe). It is not surprising that students’ understanding of why apparent motion occurs did not change given that the actual explanations for celestial motion involve complex topics such as the combination of the earth’s rotation with the orbit of the earth and the moon as well as potentially considering the shape of the earth and gravity’s role in these explanations.

If students are changing their descriptions of apparent celestial motion without altering their understanding of the reasons for this motion then either they are not primarily interpreting apparent motion as a consequent of an underlying mechanism or that the mechanism conforms easily to the new descriptions of the patterns of motion. Does this mean that the students’ initial beliefs about the world are either compatible with the scientific concepts of celestial motion or perhaps that students’ descriptions of the world are less well constrained by firmly held theories? I would suggest that both could be responsible for the observed results, in different students and different topics, though this may not agree with Vosniadou’s Framework theory of conceptual change.
Vosniadou’s theory suggests that knowledge acquisition is constrained by domain-specific principles (presuppositions) that students already have in place at an early age and that they are interpreting the world based on a complex explanatory framework (Vosniadou, 2002; Vosniadou & Brewer, 1994). It also describes alternative ideas as integral parts of the organized “mental models” held by a student, based on more deeply held framework theories. First and second grade students readily altered their descriptions of apparent celestial motion after instruction in the planetarium suggesting that for many students these alternative ideas are not highly constrained by their personal mental models nor are they firmly held beliefs. This does not exclude the possibility that the students’ reasoning about the cause of motion is not a more firmly held “theory” as described by Vosniadou.

diSessa’s model of conceptual change calls for a less systematic description of children’s knowledge structures. His theory suggests that children and novices’ knowledge of the world is better described as a loose collection of ideas. The fragmentation view of diSessa is perhaps a better fit than the Vosniadou model for describing the changes that resulted from the planetarium program. If students’ knowledge of apparent celestial motion is a loosely held together collection of observations and ideas about celestial objects, this could explain why students can show such facility in learning new ways of describing apparent celestial motion.

However, a clearer comparison between the Framework and Fragmentation theories will required a more in depth look at why the students chose the descriptions and explanations that they did, both before and after such an intervention. The discussion of Study A showed that young students are more coherent in their descriptions of why the
sun and moon disappear in the sky than older students but that they show the same level of consistency in how they describe the apparent motions of the sun and moon as older children. Investigating these differences may help us understand how to characterize the nature of children’s knowledge of astronomy and the ways their understanding changes with quality instruction.

Limitations

In this section I will discuss some of the possible limitations to this study. The first is the nature of the interview. The interview protocol required that the students have the ability to interact with the dome as a representation of the actual sky and then manipulate the flashlight to show the sun, moon and stars. Some of the students initially exhibited some confusion over the representation so it is possible that some continued to misinterpret the use of the dome and flashlight. However, much of that difficulty seems to have been the result of students’ lack of previous attempts to describe the motion of the sun, moon and stars, especially among the younger students. These students may never have thought about where the sun appears in the sky and it is likely that many of the students were in constructing these descriptions of motion on the spot. Rather than not capturing the actual nature of the students’ understanding of apparent motion due to difficulties in interpretation of the representation, as would have been the case using a different interview method, the information described in this study was limited by the students’ lack of previous experience in considering apparent celestial motion such that they lacked the deep and rich understanding needed to fully describe the concepts.

The interview setting was also highly aligned with the type of instruction that was tested in the planetarium. The students demonstrated their initial understanding of
apparent celestial motion in a dome that was much like the larger dome used in the instruction. It is likely that students had never had to describe the patterns of motion that this study was testing in any amount of detail and certainly not in the manner used in the interview. This interview setting may have helped the students learn a new way of explaining and demonstrating these motions.

This suggests the possibility that the constructivist nature of the interview itself influenced the students’ understanding of apparent celestial motion before, during and after instruction. If students had not thought through the motion of the sun, moon or stars before the interview they may have worked through some of these concepts based on other aspects of their prior knowledge during the interview. Should this be considered a limitation of this study? Perhaps not entirely. The purpose of this study was to investigate the use of a new instructional strategy in the planetarium. However, informal education literature suggests that students will gain more from field trips if these trips are not treated as stand-alone lessons (Bitgood, 1991; Price & Hein, 1991; Wolins, Jensen, & Ulzheimer, 1992). Students may show greater gains from planetarium instruction when the concepts covered in the planetarium are a natural extension of the classroom curriculum. In this scenario, the pre-planetarium interview could stand-in for classroom instruction that encouraged the student to describe their prior knowledge of apparent celestial motion to prepare them for the planetarium program. Similarly, if this program was part of lessons taking place in the classroom then students would review the concepts they learned in the planetarium (as well as extend these ideas into new areas). The post-planetarium interview therefore acts like this review in a sense. For these reasons the interview’s influence on the students’ abilities is not a major limitation to this study
because this design matches an accepted form of successful instruction that includes pre- and post-planetarium instruction.

This study only investigated the ideas of primarily Caucasian students in small towns and cities in the Midwest. Are the results consistent with other populations? Studies of children’s understanding of the shape of the earth and gravity have shown that students across several different cultures, including Israeli (Nussbaum, 1979), Nepali (Mali & Howe, 1979), Mexican American and Anglo American (Klein, 1982), and Indian (Samarapungavan, Vosniadou, & Brewer, 1996), display many of the same alternative ideas. Therefore, it may be reasonable to also expect that alternative ideas expressed by the children interviewed in this study are broadly representative ideas we might encounter from children of other cultural backgrounds, especially at the younger grades.

It would be interesting to determine whether children from cultures are more dependent on observations of the day and night sky would have improved understanding of these concepts compared to children with limited time spent observing the sun, moon and stars, such as many American children. The population of children studied here, were largely suburban rather than very urban or rural. However, it is likely that these suburban children are not spending anymore time observing the sun, moon and stars compared to their urban and possibly their rural counterparts. The culture that American children experience today does not tend to lead to the type of observations that would improve students’ understanding of the celestial motion. In many ways, eighth grade students are no more knowledgable about apparent celestial motion than third grade students suggesting that most children are not making the kind of observations of the sky that would be necessary to improve their understanding beyond that level.
However, the context in terms of geography and climate may play a larger role in influencing children’s ideas than culture or urban versus rural contexts because of the nature of apparent celestial motion. For example, a large portion of the early elementary students I interviewed held alternative ideas about the influence of clouds on the sun’s appearance in winter and a few were not certain that the sun is even in the sky in winter. We might expect that children growing up in a desert-like climate will explain the change in the sun’s apparent motion between summer and winter differently because they will not have experienced stretches of cloudy winter days. In terms of geography, a child that grows up with a significantly visible landmark to indicate a direction (such as a tall mountain range or an ocean) may learn that the sun and moon rise and set on opposite sides of the sky more readily than children without these guideposts.

This study only investigated the impact of a single lesson in the planetarium. We might have expected that for instruction to have an impact it must be sustained over a longer period of time. First, as shown in this dissertation, students can show significant improvement in all areas of apparent celestial motion after just one planetarium program. Second, the use of just one planetarium program is a more realistic model of how students actually experience instruction in the planetarium. Most students visit the planetarium no more than once per school year (at most). Therefore it makes sense to only examine the impact of a single program on students’ understanding.

Another possible limitation to this study was that there was no control group with which to compare. This does limit our ability to conclude that it was the kinesthetic learning techniques that resulted in the improvement as opposed to simply observing celestial motion or some other factor. However there is a small body of literature on the
success of planetarium programs and none of this literature addresses KLTs or apparent celestial motion. Therefore, even without a control group that would allow us to disentangle the various features of instruction studied here, this study does add to our limited knowledge of how to improve students’ understanding of these concepts. It presents a first look at the success of KLTs in the domain of observational astronomy and the use of KLTs in a planetarium program.

Finally, there was no long-term follow-up to the outcomes of this study. Examining the long-term impact of such a planetarium program is important in order to identify where students retain specific concepts and where they revert back to previous ideas. However, as mentioned before, the purpose of this planetarium program should not be thought of as a stand-alone instructional piece. Tying in these concepts to classroom instruction may enhance the students’ ability to describe celestial motion. This study demonstrated that students showed improvement in their understanding even a week after visiting the planetarium, suggesting that this knowledge is available for teachers to further develop in classroom activities and discussion.

**Future Research**

In this section, I will discuss the questions that still remain concerning children’s knowledge of apparent celestial motion, its relation to children’s understanding of actual celestial motion, and instruction around these topics. Research into these lines of inquiry will broaden our understanding of how to best help children and adults achieve an accurate understanding of apparent and actual celestial motion.

In the process of developing a possible learning progression, I have shown that there are many aspects of this concept area that require investigation in order to strength
the value of the progression or demonstrate where it should be modified. The progression is built on what we know from a few studies of children and adults’ knowledge of some of the aspects of apparent celestial motion. The support for the learning progression provided by the results of the planetarium study only helps us understand one setting with one instructional technique and with one age-level. The planetarium program was only designed to cover certain aspects of apparent celestial motion, leaving out some concepts including: the change in the moon’s rise and set time over a month, the connection between the phase of the moon and its position with respect to the sun, the fixed pattern of stars, and seasonal change in the stars location.

Smith, Wiser, Anderson and Krajcik (2006) make suggestions on how research can improve our interpretation of national standards and develop learning progressions that are relevant for proposing future research on the celestial motion progression. First, they suggest that research can help us elaborate on the necessary prerequisites to the standards. I began this process in the description of the learning progression. The elaboration of necessary underlying knowledge was based partly on the types of descriptions given by students about their understanding of celestial motion at different grade levels and partly based on my conceptual understanding of these topics. Future work that closely examines how individual students’ ideas change based on instruction can help us more accurately describe the prerequisite ideas and explain why they may be important for students’ development of these concepts. For example, one of the most challenging aspects of the apparent motion of the moon is that it rises and sets about 50 minutes later everyday. Future work that establishes the important prerequisite knowledge (such as understanding the moon’s path or its orbit around the earth) could
help us design instruction as well as decide at what grade level students will be ready to understand the concept. This could be established by examining how students improve in their understanding of the pattern of the moon’s rise/set times after receiving instruction on various assumed prerequisites.

Second, further research is needed to identify connections between the big ideas of apparent celestial motion and other areas of the standards (Smith, Wiser, Anderson & Krajcik, 2006). The most obvious connection is between apparent and actual celestial motion. I would suggest that this is one of the most important areas of future research in elementary astronomy education: how does knowledge of apparent celestial motion effect how children learn the explanations for that motion? Much of the astronomy education research to date has shown that children and adults have alternative ideas on many aspects of how the sun, earth, moon, stars and planets actually move and interact. By examining how understanding of apparent celestial motion may or may not be an important prerequisite for understanding these objects actual motion we may find more successful ways of teaching these concepts. Research in this area will allow us to create a learning progression that connects concepts of actual and apparent celestial motion and places these concepts at the appropriate grade levels.

Finally, Smith, Wiser, Anderson and Krajcik (2006) suggest “research can provide empirical evidence of the age appropriateness of standards, particularly in the form of teaching experiments demonstrating that typical students in a certain grade range can learn a standard with proper instruction” (p. 7). This is especially important in going beyond just a suggested sequence of concepts along the learning progression but to establish when it is most appropriate to address these concepts and in what instructional
conditions. The planetarium program was highly successful in helping first and second grade students learn many of the patterns of motion, but would children at that age level be as successful with instruction that is not set in such a visually stimulating environment? And at what grade level would the majority of students be able to understand the more advanced concepts described in the learning progression? Much additional work is needed to determine whether some concepts need to wait until upper elementary or if the students would be capable at a younger grade level if they understand the necessary prerequisites.

I described elementary and middle school students’ beliefs about apparent celestial motion. But how are these ideas expressed by adults, elementary school teachers in particular? Mant and Summers (1993) examined some of these concepts with elementary science teachers and found some similarities with the eighth grade students in my study and some differences as well. These differences may be due to the age of the subjects, their education level, or the methodology used in the studies. Investigating this further will show the areas that we can help teachers improve in to provide them with the necessary content knowledge that will allow them to help their students. In a related vein, we may wonder how alternative ideas about apparent celestial motion may inhibit or complicate learning about other more “advanced” topics of astronomy. Do older students, such as students in an introductory college astronomy class, exhibit the same patterns of knowledge of these topics as the eighth grade students? And what is the impact of their alternative ideas of apparent celestial motion on learning about other topics of astronomy?
A few of the limitations of Study B could be eliminated with further research into the use of kinesthetic learning techniques in the planetarium. One area to investigate is the impact of pre- and post-planetarium instruction on the students’ improvement both immediately after instruction and as well as after several months. Such research could potentially identify strategies that will help students show greater improvement after the planetarium program by teaching prerequisite concepts to those areas of celestial motion. Such a study could also utilize a control group by examining how well students learn from a similar program that does not use KLTs.

**Concluding Remarks**

The two studies in this dissertation were designed to examine children’s knowledge of the topics of astronomy covered by the *NSES* and *Benchmarks* for early elementary school as well as examining whether or not young children are able to improve their understanding of these ideas through instruction in a planetarium program. Elementary and middle school children often describe the patterns of apparent celestial motion in non-normative ways, though in many topics older students show increasing accuracy. The planetarium program, by engaging the students with kinesthetic learning techniques, was found to be successful in helping students improve their knowledge and should be recommended to planetariums offering programs to children learning about celestial motion.
APPENDICES
Appendix A: Images for pilot testing scenario 1

Sun, moon and landscape images above are not displayed at the same scale as during the pilot testing interviews.
Appendix B: Interview record sheets

Date ________________
ID ________________

Gender: M  F
Grade: 1st  2nd
DOB: ________________

What do you like to do outside in the summer time?
1. Can you show me where the sun is first thing in the morning?
2. What about a little later in the morning – where is the sun?
3. Where is the sun at lunchtime?
4. Where is the sun in the afternoon around when school is done?
   Now let's imagine that it's the end of the day.
5. What happens to the sun at the end of the day? Show me.
6. Can you show me again how the position of the sun changes?
   Remind that we are pretending that it is summer.
7. Point to where the sun will be when it is highest in the sky.
8. Is that directly over head?
Now let’s pretend that it is winter time.
What do you like to do outside in the wintertime?
1. Can you show me where the sun is first thing in the morning?
2. Where is the sun later in the morning?
3. And at lunchtime?
4. Where is the sun when school gets out?
5. Show me what happens to the sun at the end of the day?
Remember that we are pretending that it is winter time right now.
6. Point to where the sun will be when it is highest in the sky.
7. Is that the same as it was in the summer?
1. Can we ever see the moon during the day? Pretend that it’s night time. Explain the flashlight as the moon.
2. Where might we see the moon after sunset?
3. Where is the moon at midnight? Go to bed but get up while it’s still dark outside.
4. It’s still dark out but it’s almost time to get up. Where is the moon now?
5. And where will the moon be when we see the sun again in the morning?
6. Does the moon always set when the sun comes up?
7. Where does the moon go when you can’t see it?
8. Show me how the moon changes where it is during the night.
Pre-Planetarium Interview
Date __________________
ID __________________

Let’s talk about the stars now.
1. Do the stars move in the sky during the night?
   Pretend it’s night with stars. Right after sunset.
   Let’s pretend we can see a bright star right over here.
2. Where will we see that star around midnight?
3. Where will we see that star right before sunrise, while it is still dark out?
4. If we went outside now and looked at the sky, before the sun comes out,
   would we see the same stars as you saw right after it got dark?
5. Would the stars be in the same place?

5. Where are the stars during the day?
6. Where is the sun when we can’t see it in the sky?
7. What’s going to happen to make it daytime?
Appendix C: Planetarium script

Introduction

- Explain that the dome is going to be the sky
- Ask students to think about what they see in the sky
  - “What objects do we see in the sky?”
- Explain that the planetarium projector will show us all of the things that we would see in the sky during the day and the night. I will be pushing buttons on the other side of the console to turn on the lights that show these objects and then move the objects across the sky.
- Explain to the students that in the planetarium we can show things happening very quickly that really happen very slowly.
- Explain that the planetarium machine will spin like the earth spins so that we will see the same thing just like we see because the earth rotates
  - Use earth globe

The Apparent Motion of the Sun in Summer, Part I

- Tell the students that we are going to pretend that it is the first day of summer, June 21.
- Intro questions:
  - “What makes it daytime? Why is it light outside during the day?”
  - Where would you look for the sun first thing in the morning?
  - Would it be low or high in the sky?
  - Does anyone know what direction the sun is when it rises in the morning?”
- Turn on the sun and point it out in the sky.
- “Does the sun seem to move in the sky during the day?”
- Use your hands and arms to show me how the sun moves in the sky.
- Turn on daily motion - Remind students that we are watching time go by quickly and that the motion we see is because the earth is rotating.
  - Students trace motion with hands and arms.
  - Show the sun rising in the east, passing through the south and getting low in the west.
- Ask the students “What time of day is it when the sun is low in the sky like this?”
- Ask them “What will happen now? Show me what will happen by pointing.”
- Turn on daily motion. Show the sun setting. Remind the students that this motion is caused by the earth spinning. The sun sets when we spin away from the earth.

The Apparent Motion of the Stars, Part I

- After the sun sets, turn down blues and turn on stars. Do this slowly. Students should watch for the first stars to come out. These are the stars we see just after
sunset.

- “Do we see the same stars late at night?”
- **Run daily motion** – show the sky at midnight.
- “Point to where new stars rise. Point to where the stars set.”
- Stars rise and set because the earth spins around to face them or face away from them.
- “Trace with you arms what the stars are doing. Pick one star bright star and follow what it is doing.”
- Stop just before the sun is about to rise.
- “At the end of the night, what happens?” The sun rises. “Where is the sun going to rise? Everyone point to where they think we will see the sun again.” “Show me what the sun is going to do over the course of the day.”

**The Apparent Motion of the Sun in Summer, Part II**

- **Run daily motion again.** Observe the sun to rise and set again. Students trace the motion with their arms.
- Stop at noon.
  - “What time is it?”
  - “How high is the sun? This is where overhead is in the planetarium sky. Is the sun up there? No, so it’s not directly overhead even in the summer.” Have students point to the zenith and the position of the sun.
- “Where is the sun going to be in the afternoon when school gets out?”
- “Where is the sun going to set?”
- **Run daily motion.** Watch the sun set again.

**The Apparent Motion of the Stars, Part II**

- **Find the Big Dipper.** Students trace the shape in the sky. Students count the stars along with me.
- **Find the North Star.** Students follow the pointer stars to the North Star. Find the directions N, S, E, and W.
- Tell the students we are going to play a little game. But first they will need to learn some constellations. Good summer constellations/stars to use: Dolphin, Vega & the Harp, Arcturus & Bootes, Antares & the Scorpion.
- **Run daily motion.** Watch the motion of each of these objects. Students pick one of the objects and trace it’s motion until it sets
- Stop just before sunrise
  - “Could you see your star or constellation all night long?”
- Let the sun rise.
- “We have now seen the sun rise and set twice so how many days has it been?” Two days.

**The Orbit of the Moon**

- Haven’t seen the moon yet. Some days we don’t see the moon in the sky at all.
- Bring out moon ball. Have volunteer hold the earth globe. Show moon’s orbit around the earth.
Moon’s orbit is about 28 days or one month.

- Moon moving slowly around the earth
- At the same time the earth is rotating. So half of the time our side of the earth is facing the moon.
- Everyone stands up to pretend they are the earth spinning around.

**The Apparent Motion of the Moon**

- “Where will we see the moon when it first rises?”
- **Turn on moon**
- **Run daily motion.** Show the crescent moon rising and setting, with the sun also in the sky.
  - “Let’s watch the sun rise again and wait for the moon to rise too.” **Run daily motion** until the moon gets high enough that the students can all see it clearly.
  - “Is it day or night?” We can see the moon and the sun in the sky.
  - Notice that the side of the moon that is lit up is the side facing the sun.
  - “Point out in the sky what you think the moon is going to do during the rest of the day.”
- Have kids trace the motion of the moon in the sky while pointing at the sun as well.
  - Make sure they notice that the moon moves with the sun.
- **Stop daily motion after the sun sets and it gets dark**, but with the crescent moon still in the sky.
  - “Did the moon change its shape while it was up in the sky?”
- “Does the moon always look the same in the sky?” Show some pictures of what the moon looks like at different times of the month.
  - Show slides of the waxing crescent, 1st quarter moon, and full moon.
- “I am going to change the date on the planetarium. We are going to move ahead 3 days and see what the sun and moon will do 3 days from now.”
- **Run the moon ahead to 1st quarter.**
  - Watch the sun rise again. “Where will the moon rise? Everyone point where they think.” **Wait for the moon to rise.**
  - “Does the moon look the same?”
  - “Does the moon move across the sky the same?”
  - **Continue the motion** so they can see that it stays in the sky for a while after sunset before setting.
  - “Did the shape of the moon change as it moved across the sky?”
- Repeat the process for the Full moon. Point out that this about 1 week later, and almost two weeks after the first time we looked at the moon.
- As the moon orbits the earth, it gets farther from the sun in the sky. And when it is far from the sun in the sky, we see more of the moon lit up.
- When moon is full, it is opposite sun in the sky. We see it all night long.

**The sun later in the year.**

- **Turn off the moon projector**
- Now we’re going to talk about what the sun will do in the Winter
○ Turn on ecliptic and move the sun to Dec. 21

- “Do you think that the sun’s motion in the sky will be the same in the winter as it was in the summer? How might it be different?”
- “Now point to where you think the sun will be at noon.”
- “Now, where is it going to set?”
- **Observe the motion of the sun in winter.** When sun reaches the south, ask the students “Is that the same as when it was summer? Point to the sun’s position at noon in the summer.”
- Did we ever see the sun right over head?

The stars today

- Show tonight’s sky


