Toward a Framework for Integrating Planetarium and Classroom Learning

by

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DEDICATION

To my daughter Veda Penelope Daria Schinke, whose imminent arrival while writing gave me the motivation to finish this dissertation with no help from coffee whatsoever.

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ABSTRACT

Field trips are a ubiquitous part of modern school programs and can offer exciting, engaging, and authentic experience for students to learn science. There has been extensive research on how to best integrate field trips with classroom instruction so they can reach their full potential. Planetaria are often ignored in this literature, which is unfortunate as they are more didactic and structured environments than other informal spaces such as museums, but can still offer positive affect and learning gains to students outside of the classroom. The goal of this dissertation is to explore the unique aspects of learning in planetaria as informal settings. This is done by testing a curriculum on apparent celestial motion that integrates the planetarium and classroom environments based on the School-Museum Integrated Learning Experiences in Science (SMILES) (Griffin, 1998) framework for integrating classroom and museum learning. Data in the form of interviews, class work, audio-visual recordings, and surveys were analyzed using qualitative and quantitative methods to find examples of the 6 strands of informal learning (National Research Council, 2012) and suggest revisions to the SMILES framework for use with planetaria. The results showed examples of all 6 strands of informal learning, suggesting the SMILES framework was appropriate for planetarium field trips. However, weaknesses in students' descriptions of apparent celestial motion, reasoning skills, social interactions, and language use suggested revisions to the SMILES framework for use with planetaria. These revisions included addressing choice and control normally seen in museum settings in the classroom, preparing students for language in addition to concepts seen while on a field trip by providing teachers with a script or list of vocabulary to be addressed in context, have students

collect data from the show and explicitly use it with scientific practices the classroom afterward to support multiple exposures to ideas and help them avoid using authority of facts gathered at the planetarium as a sole means of justifying answers, model specifically those scientific practices in the classroom, and address a single overarching topic in planetarium show or delineate changes between topics to avoid confusing students.

Chapter 1

INTRODUCTION

Planetaria are useful cognitive tools for people learning about the night sky, apparent celestial motion, and even deep space (Manning, 1996). They can accelerate motions and changes in the sky, making them more apparent and easier to understand (Lomb, 2005). With their ability to show the night sky accurately during the day, they are also convenient for teachers to teach astronomy while being constrained by normal school hours. As a result of the space race of the 1960s and America's desire to compete in science fields, planetaria have traditionally been situated in schools where students could easily visit multiple times a year. These are becoming less prevalent each year due to budget cuts, making single field trip visits to planetaria the more common means of accessing their benefits. However, how to best utilize planetaria as *informal* spaces, especially when combined with formal astronomy instruction, is not well understood. This dissertation strives to expand our knowledge on how to best incorporate planetarium field trips into formal astronomy education by applying existing guidelines on the integration of museum and classroom learning environments and to determine modifications for use with planetaria. This chapter will introduce the rationale and research questions that guide this dissertation.

1.1. Rationale

1.1.1. Benefits of Informal Learning

As science and technology become a larger part of our economy, having a public that understands and uses science is paramount in order for them to participate in a larger dialogue (National Research Council, 2007). As a result, it is expected that K-12 students learn multiple disciplines of science, including astronomy (American Association for the Advancement of Science, 1993; National Research Council, 1996, 2012). Informal environments, commonly including museums, zoos, aquaria, nature centers, as well as planetaria are apt to support learning of this content through their partnerships with scholarly institutions as they have a dedicated staff for building exhibits and programming that can more efficiently adapt to frequent changes than textbooks.

Beyond understanding content, people need to understand the processes and modes of “doing science”. Museums are able to offer immersive experiences where visitors can participate in scientific practices in a more authentic manner than schools may be able to offer (National Research Council, 2007, 2009, 2010). Authentic experiences in science are key due to the situated nature of learning where people learn through productive participation in activities (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). For instance, museums can create specialized exhibits that allow visitors to work through the inquiry process of past research and “rediscover” the facts for themselves using actual scientific tools (Hein, 2000). Though visitors are not conducting new science, they are able to gather authentic experiences of doing science beyond resources schools can necessarily offer.

In order for people to actually learn they need to be engaged with the material. Informal learning spaces are recognized by educators for their ability to inspire interest and excitement in students for topics they may have never expressed interest in before (Eshach, 2007; Kisiel, 2005; National Research Council, 2009, 2010). Students have also reported greater interest in learning science through museum exhibits and see themselves as having learned more as a result (Flexer & Borun, 1984; Griffin & Symington, 1998; Price & Hein, 1991; Schauble, Leinhardt, & Martin, 1997). The museum experience can act as a catalyst for further learning beyond the museum walls through the interest, excitement, and wonder they inspire (Anderson, Lucas, & Ginns, 2003). This interest and excitement can in turn can further a students engagement with material back in school or on their own at home.

One reason why museums are so inspirational is because they are characterized by free-choice and self-directed learning where visitors are in control of their learning episodes. People are free to move around an exhibit space as they choose and learn about topics they find most interesting, thereby personalizing the experience and making it more meaningful for each individual (Banz, 2008; Eshach, 2007; Falk & Dierking, 2000; Hofstein & Rosenfeld, 1996). Choice and control helps people become more motivated to learn, which in turn can help in knowledge construction that occurs at the museum or beyond (Falk, Dierking, & Adams, 2006; Pintrich, Marx, & Boyle, 1993; Ramey-Gassert, Walberg, & Walberg, 1994).

Additionally, museums are democratic environments for learning that use more visually stimulating means of communicating information. Museums can potentially engage a variety of different learners who may normally avoid more educational outings (Yasko, 2007). Furthermore, teachers who see changes in their more disengaged students may change their attitudes on how to best support student learning in science back in the classroom (Price & Hein, 1991). There is great potential for museum field trips to inspire and initiate changes in student and teacher behaviors and attitudes toward learning, which can in turn affect content understanding.

1.1.2. Challenges for Informal Learning

Despite the affordances of informal learning environments, they often fall short of their potential. Informal environments are generally characterized by choice, control, and autonomy in learning. However, students still need some support in their learning, particularly when learning across informal and formal settings (Cox-Petersen & Pfaffinger, 1998). That support is often minimal because of lack of communication between museums and because teachers are generally overworked and not given proper overview of what is at the museum and how it can tie to their curriculum (Griffin, 1994; Griffin & Symington, 1998; Kisiel, 2003; Lucas, 1998).

Many teachers do not prepare their students for what they will be seeing while at the museum, which is unfortunate as students can become cognitively overwhelmed due to the novelty of the space (Balling & Falk, 1980; Orion & Hofstein, 1994; Ridky, 1975). This causes more of a student's cognitive abilities to be placed in processing the physical space around them rather than content. Students are also not given a purpose and the unstructured environment can result in off-task behavior (Kisiel, 2003b).

While at museums many teachers will not engage their students or model how they should learn (Griffin, 1994; Lelliot, 2007). They will sit on the sidelines and allow their students to amble about. This is despite that fact that many teachers report that their job is to facilitate learning in some way (Tal, 2001). Students are also not often given much structure in what they are doing at the museum and are expected to learn on their own. Even when given tasks such as worksheets, it is often passive or similar to a scavenger hunt rather than prompting students to reflect on what they see (Griffin & Symington, 1998).

Finally, students are not given post activities that allow them to continue their learning beyond the museum. Teachers often report they plan on doing follow-up after the field trip (Griffin & Symington, 1998; Kisiel, 2003b). However, if any discussion does occur, it is most commonly a discussion of what students saw without an application of what they found out. Any feedback given on worksheets is similarly lackluster and graded based on completeness (Griffin, 1994).

Museums could also be more supportive of teachers as they rarely have the time or resources to fully understand what museums offer or how to utilize the exhibits and attractions. However, it has been shown that teachers and museums rarely communicate beyond administrative capacities (Tal & Steiner, 2006). This lack of communication can result in frustrated teachers who do not think their students are getting the experience they need to learn certain topics, even if they did prepare students in some way (Kisiel, 2003b; Lucas, 1998). For meaningful learning to occur, museums and schools need to find ways of communicating what is needed and what can be provided from each side. Museums should provide teacher support in creating pre- and post-activities that best fit the students needs and the affordances of the environment as well as orienting teachers to what the museum has to offer (DeWitt & Osbourne, 2007; Griffin & Symington, 1998; Griffin, 1998; Kisiel, 2005).

1.1.3. Frameworks for Supporting Learning Across Contexts

In response to these roadblocks to learning in informal settings, there have been some frameworks that suggest guidelines on developing curriculum to support learning across contexts. These include the School-Museum Integrated Learning Experiences in Science (SMILES) (Griffin, 1998) and the Framework for Museum Practice (FMP) (DeWitt & Osbourne, 2007). The frameworks offer similar guidelines, but SMILES is geared more towards teachers and offers more specific curriculum structures while FMP is structured more for museums and has a greater focus on teacher support. These frameworks are based on socio-constructivist theories of learning and are discussed more extensively in the next chapter.

Falk and Dierking's (2000) contextual model of learning is similarly based on socio-constructivist theories of learning and stems from a museum perspective. This model states there are three contexts in which people learn: the personal, sociocultural, and physical. These contexts are important to address across learning settings and can help justify features in the SMILES and FMP frameworks. The personal context accounts for students' prior knowledge, experiences and unique interests. Both SMILES and FMP recommend that student choice in learning episodes should be fostered across learning environments, particularly in museums. The sociocultural context recognizes that students also learn well with others, including peers and adult facilitators. Each framework encourages formation of groups of students who work together, but are also facilitated by an adult during their learning. Finally, the physical context can result in novelty effects mentioned earlier (Balling & Falk, 1980). To address this, both recommend pre-activities that prepare students both physically and cognitively for what they will see during the trip as well as post-activities that continue to support student experiences beyond the museum walls.

These frameworks have been applied to creation of curricula that include field trips with relatively high success (DeWitt & Osbourne, 2007; Griffin, 1998). However, neither framework has been applied to astronomy curricula that use a planetarium field trip. Planetaria are very different learning environments and as a result need further research that focuses on their unique difficulties and spaces.

1.1.4. Planetaria as Informal Learning Environments

Informal learning environments, when used appropriately and in ways that counteract issues such as lack of communication and tying learning across settings, can be a useful boon to formal education. This previous work is not entirely inclusive of all informal learning environments. Namely, planetaria are very popular informal learning environments but have notably unique characteristics from informal environments. However, most of the time planetaria are only passively mentioned in the literature and not studied independently from other informal environments.

Planetaria are wonderful environments for people to learn basic concepts about astronomy. Many of these concepts, such as apparent celestial motion, lunar phases, and positions of objects in the sky are key concepts people are expected to know by the end of elementary school (American Association for the Advancement of Science, 1993; National Research Council, 1996, 2012). Many of these topics are difficult for people to visualize because they happen slowly over hours, days, or even months. This results in misconceptions on these ideas for both adults and children (Nussbaum, 1985; Plummer, 2007; Starakis & Halkia, 2010; Vosniadou & Brewer, 1992, 1994). Since planetaria can speed up celestial motions and changes, they become more apparent. Planetaria thus offer a very useful and immersive environment for teaching basic astronomy concepts through direct observation.

Though planetaria are useful informal learning environments, they are not the same as all others such as museums, zoos, aquaria, etc. Informal learning environments are characterized by being unstructured, un-sequenced, open-ended, choice driven, and incorporating personal and social interactions, while formal learning is characterized by being structured, sequenced, teacher-led, impersonal, and more solitary (Eshach, 2007; Falk & Dierking, 2000; Hofstein & Rosenfeld, 1996). Planetaria are considered informal environments because they are out of school and offer an exciting and immersive experience that students cannot often experience at their school. However, they are more passive experiences because they provide short (~30-60 minute), pre-determined, scripted shows given to whole groups of 20-150 people at time. In this way, their characteristics are more aligned with those of the formal learning environments than informal. Planetaria are dark and confining rooms, which limit social interactions and any common field trip activities such as worksheets. Since planetaria are informal learning environments that include aspects of formal learning they should studied as a unique case.

Most previous research on planetaria focuses on installations that were housed within school environments when those were more prominent in the 1970s. More modern research that does look at the informal planetaria focus on their effectiveness or how to best visualize data. However, there is almost no research that exists on integrating planetarium learning with classroom learning.

1.2. Research Questions

Planetaria are informal learning environments that, today, often exist outside of school and that students will visit as part of a field trip. As such, much of what is already known about integrating informal and formal learning should readily apply to planetarium learning. However, planetaria are unique even as informal learning environments, so how to support learning amongst those differences needs to be understood. This dissertation looks to address the lack of research that exists on integrating planetarium and classroom learning.

I have taken the existing SMILES framework discussed above and applied it to the construction of an integrated curriculum on the apparent motion of the sun and moon.

I then evaluated how well the SMILES-based curriculum supported learning across contexts based on the six goals or "strands" of informal learning as defined by the National Research Council (2010):

1. Sparking Interest and excitement
2. Understanding Scientific Content and Knowledge
3. Engaging in Scientific Reasoning
4. Reflecting on Science
5. Using Tools and Language of Science
6. Identifying with the Scientific Enterprise.

The SMILES framework was chosen rather than another framework such as FMP, because it was designed specifically to address curriculum development that could potentially be used by teachers or museum educators. Additionally, the guidelines offered are descriptive of the nature of activities. For instance, it states that pre- and post-activities should offer purpose to students rather than simply stating that pre and post activities should exist. Furthermore, the guidelines are meant to be flexible to address a variety of informal environments. Thus, we can test out how flexible it is for planetaria.

The research questions I address are:

RQ1. What examples of the 6 strands of informal learning are seen during the implementation of a SMILES-based curriculum that integrates learning across planetarium and classroom contexts?

RQ2. How do the examples of the 6 strands of informal learning suggest revisions to the SMILES framework in order to be more usable with planetaria?

The first RQ looks at if SMILES can easily translate to planetarium learning in the first place and if we can still successfully apply it such a different informal learning environment. The second research question uses the results of the first to offer suggestions on changes that might make the SMILES framework and other frameworks more appropriate for planetaria.

1.3. Contributions to the Field

Research on both planetarium and museum learning suggest that integrating instruction across the contexts can lead to more positive outcomes in terms of students' level of understanding and interest in science. This study aims to understand how we can more appropriately utilize planetaria as part of formal astronomy learning through the implementation and evaluation of a SMILES-based astronomy curriculum that integrates a planetarium field trip.

This work will address the lack of research on how to support learning in planetaria, particularly when combined with formal classroom instruction. It will also identify challenges that are associated with more structured informal learning environments, which tend to be ignored in informal learning literature. A successful curriculum will also offer teachers and museum educators a set of activities that can be modified for use for their own district's learning standards and planetaria and in light of the challenges uncovered as part of the study.

The results of this research will also include a revised set of flexible guidelines for how to successfully build integrated curriculum for planetaria. These guidelines will be based in theory and findings from informal education, but also make apparent the differences between different informal learning environments that need to be addressed. The flexibility means both museum educators and teachers will be able to use the new guidelines to help students gain the most out of field trip experiences in a variety of content areas. It could also be used with different types of planetaria that vary in size, projection methods, and use of live operators and docents.

The findings will have the most direct applicability to planetarium learning; however the lessons learned might have implications for any show-based learning that commonly occurs in museum settings. For example, science centers often have interactive shows with actors, docents, or interpreters that can demonstrate varying concepts that may need more supervision than a typical exhibit (e.g. live scripted presentations about electricity). These are also more structured like planetaria, but they are still more informal than a classroom. The results on more structured planetaria can potentially have lessons that translate to these other kinds of shows housed in museums.

1.4. Summary

This chapter introduced the importance of informal environments in helping students learn about various science topics. Specifically, informal learning spaces can offer students experiences that help emphasize modern science education goals that include students gaining a sense of how science is "done". Museums and similar spaces offer chances for students to engage in authentic science experiences while motivating them to learn beyond the visit by allowing choice in learning episodes according to their interests.

Despite the affordances, it is also recognized that students need some support in learning across classroom and informal settings. Students need to have preparation for the topics they will be seeing and have some focus for how their visit is important to what they are learning. Teachers also need support in helping their students gather useful information at the museum and use it back in the classroom, as they do not always understand how to best fit the visit into their curriculum. How to best offer this support to students and teachers while maintaining the affordances of the informal learning space has been studied extensively within museum settings. This work has resulted in a series of helpful guidelines for museum practitioners and teachers on how to develop curricula that supports student learning across settings.

Planetaria are popular informal learning spaces, but their characteristics are different from museums. Museums are characterized by choice and control, and they have the ability to support social learning. Planetarium shows, however, tend to be more structured and less personal. Though they can have elements of choice, control, and social learning, they do not necessarily exhibit these characteristics to the same extent as museums. As a result, I argued planetaria should to be studied separately, but in light of previous work and guidelines to find how to best support learning during planetarium field trips.

Chapter 2 will offer a review of the literature and relevant theories on planetarium learning, museum learning, and describe the 6 strands of informal learning used as evaluation criteria. Chapter 3 will summarize the curriculum design and the methodology used to evaluate the curriculum and answer the two research questions. Chapter 4 will present results for research question 1 by strand of informal learning. Chapter 5 will offer discussion on the results and how they applied to SMILES and the suggested revisions. Chapter 6 will discuss limitations of this study, future work, and offer a summary of the dissertation.

Chapter 2

LITERATURE REVIEW

2.1. Overview

This dissertation is looking to identify the similarities and unique aspects of visiting planetaria in informal contexts as part of more formal astronomy curriculum. This was done by designing and testing a curriculum for apparent celestial motion. This chapter will review the literature that informed this study and situate this work in the larger context of informal science learning.

Previous work on planetarium learning, its effectiveness, and its use as both a formal and informal learning environment will be discussed first. Next, the SMILES framework used in designing the curriculum and will be introduced in more detail and act as an entry point to discuss the theory and research in integrating learning across contexts that were used both in the building of SMILES and this study. Finally, each of the 6 strands of informal learning used as evaluation criteria for the curriculum will be discussed in terms of what they address and why they are important within science education.

2.2. Planetarium Learning

The *National Science Education Standards* (National Research Council, 1996), *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science, 1993), and the *Framework for K-12 Science Education* (National Research Council, 2012) all state students should be able to describe the apparent motion of the sun, moon, and stars and the lunar phases by the end of elementary school. The observations necessary for people to accurately describe these motions happen slowly over hours, days, or even months and are easily overlooked in everyday life. As a result children and adults often have alternative ideas about basic astronomy concepts such as the sun rises and sets in the same place every day, the sun goes through zenith everyday at noon, or the moon is only seen at night (Mant & Summers, 1993; Nussbaum, 1985; Plummer, 2007; Sharp, 1996; Starakis & Halkia, 2010; Vosniadou & Brewer, 1992, 1994). Planetaria can easily recreate the night sky for any date, time, or location on Earth and can speed up apparent motions, making them more obvious (Lomb, 2005; Manning, 1996). Additionally, planetaria are spaces that can inspire wonder and curiosity that visitors can take home with them (Manning, 1996; Small & Plummer, 2010). Unfortunately, there has been very little recent research done specifically on the effectiveness of planetaria for learning, particularly when combined with classroom instruction (Brazell & Espinoza, 2009; Lelliot, 2007). Despite this lack of research on planetarium effectiveness, there are studies on stand-alone planetarium shows and on combining planetarium and classroom instruction that are informative.

2.2.1. Stand-Alone Planetarium Show Effectiveness

There have been some studies in the past few decades that have looked specifically at the effectiveness of a single visit to a planetarium in increasing people's apparent knowledge about astronomy. These studies tend to focus on the nature and features of a planetarium show that make it effective.

Mallon and Bruce (1982) tested 556 random students between the ages of 8 and 10 with written content questions and Likert-scale attitude surveys after they visited one of two different shows. The first was a more traditional, didactic, and scripted “star show” where students were simply shown constellations in the night sky. The second was a participatory show that allowed visitors to extensively interact verbally with the show’s operator rather than follow a strict script. The results showed more significant gains in students’ content and affective scores in the participatory program rather than the traditional star show, suggesting that programs where visitors can interact in the show in some way are more effective.

Similarly, Plummer (2007) looked at effects of a single 45-minute planetarium show in 1st and 2nd graders’ descriptions of apparent celestial motion using a different participatory method known as kinesthetic learning techniques (KLTs), where learning is matched with movement. During the show, students pointed at objects and moved their arms as they moved across the sky to help focus attention. A total of 63 students were then interviewed about their views of apparent celestial motion before and after the planetarium show. The results showed that students significantly improved their descriptions of apparent celestial motion; however most did not describe completely normative ideas. This suggests that KLTs and participation in some form are effective qualities of a planetarium show. However, to help students gain fully normative knowledge, they would need additional instruction that would likely occur in the classroom.

Lelliot (2007) conducted qualitative case studies using pre and post-interviews, audio-visual recording of students, personal meaning maps and field notes of 12-15 year old South African students before, during, and after they visited a planetarium/science center or a Radio Observatory. Overall, students displayed greater interest towards astronomy and displayed some desire to learn more astronomy after the field trip. Students also displayed better understanding of what Lelliot (2007) referred to as “Big Ideas” on gravity, the sun, stars, and astronomical scales. However, students also showed little change in their knowledge regarding lunar phases and the day/night cycle. The short-term improvements seen were achieved despite the teachers often not engaging the students in any way while on the field trip. Lelliot (2007) showed that planetaria were successful in getting students to gain astronomical knowledge in several, but not all areas of astronomy content, even without strong connections back to the classroom. However, this study involved larger science centers where students were free to roam other exhibits related to astronomy before and after their planetarium show. Thus, this research shows promise for planetarium learning as an informal environment, however it is difficult to tease out the effects specifically linked to planetaria.

Overall, these studies suggest that single informal planetarium visits are useful in helping students improve their attitudes towards astronomy and motivating students to learn more. Students across all three studies also improved their descriptions and knowledge of astronomical concepts. Participatory methods such as KLTs (Plummer, 2007) and discussion between the audience and operator (Mallon & Bruce, 1982) were also shown to be particularly effective in teaching students astronomical concepts, suggesting that planetarium shows should incorporate some participatory element. However, students in Lelliot (2007) and Plummer (2007) did not display fully normative knowledge related to what was seen in the planetaria. This suggests that students may need further instruction in the topics back in the classroom to help them gain normative ideas in astronomy.

2.2.2. Planetaria and Classroom Learning

There has been extensive research done on comparing classroom instruction with planetarium instruction of astronomy concepts. Reviews of the results show them to be mixed with some studies suggesting that planetaria are as effective or more effective environments for teaching astronomy and others suggesting that classroom only instruction is superior (Brazell & Espinoza, 2009; Lelliot, 2007; Sunal, 1976). Brazell and Espinoza (2009) conducted a meta-analysis of 19 studies that tested planetarium versus classroom instruction in order to sort out these disparate results. Their results showed that planetaria were effective environments for teaching students astronomy, particularly those in elementary school. They also noted that classroom and planetarium instruction that emphasized and encouraged participatory observational aspects of astronomy showed higher gains than those that focused on lecture type instruction, consistent with Mallon and Bruce (1982) and Plummer (2007). Finally, studies that used a single planetarium visit as opposed to multiple visits showed greater positive effect sizes.

Sunal (1976) also conducted an analysis of 9 studies on school planetarium effectiveness and if they reach the perceived goals of educators. His synthesis also suggested that planetaria were effective in helping students reach learning goals, though classroom lessons were more effective than single planetarium visits and the benefits of planetaria in astronomy education seem focused on the affective realm. Planetarium visits also found to be most effective when combined with classroom instruction and when there are multiple visits to the planetarium, including one visit that helps students orient themselves in the space.

The work by Sunal (1976) and Brazell and Espinoza (2009) suggest that planetaria are effective in teaching students astronomical concepts and improving attitudes toward astronomy. However, they also included mostly studies that simply compared planetarium instruction to classroom instruction. As Sunal (1976) noted along with the literature on effectiveness of single planetarium, combining classroom and planetarium instruction results in higher conceptual and affective gains. There are a few studies that looked specifically at effects of combined classroom and planetarium instruction.

First, Ridky (1974) tested the effects of planetaria on student understanding of daily motions. He studied 8th grade and college students by putting them into three conditions: planetarium instruction only, classroom instruction only, and a combination of planetarium and classroom instruction. Students were given conceptual and attitudinal tests related to the curriculum. He also gave a test 6 weeks after the intervention to test retention of knowledge. The results showed there was not a significant difference in student knowledge between the planetarium only and classroom only conditions. However, there were significantly higher gains for both conceptual and affective learning as well as retention of knowledge from students in the combined group, suggesting that combining instruction across the two settings is more effective.

Sunal (1973) conducted a quantitative study on several groups of 2nd graders as they learned basic astronomy concepts. He evaluated children with pre and post-tests after they were placed in one of three conditions: planetarium and classroom instruction, only classroom instruction, and no astronomy instruction as a control. He showed that students who had the combined classroom and planetarium instruction had significantly higher gains on the post-test than the control group. Unlike Ridky (1974), he showed a significant increase in understanding from students who received only classroom instruction over the planetarium and classroom condition. This suggests that for conceptual understanding, students may benefit from only classroom instruction in astronomy. However, Sunal (1973) also showed that students who visited planetaria along with formal astronomy instruction showed higher affective gains over students who were only taught in a classroom setting. This suggests that it may still be desirable to include planetarium instruction to help motivate students to learn astronomy.

More recently, Sarrazine (2005) studied 6 groups of students learning lunar phases in several conditions including a single planetarium visit, a classroom lesson before a planetarium visit, a classroom lesson after a planetarium visit, and a classroom lesson before and after a planetarium visit. There were two versions of the classroom lessons that were also tested and all lessons were within a week of the planetarium visit. All activities and the planetarium shows were also designed to address various types of learning styles according to Multiple Intelligences theory, which states that people can learn in a variety of ways including linguistic, musical, bodily-kinesthetic, spatial, inter or intrapersonal, or naturalist (Gardner, 1999). Sarrazine (2005) used a 25 multiple-choice pre- and post-test in order to test students' level of astronomy knowledge. She found that students in all conditions showed significant gains and there was no difference between classroom instruction either before or after the planetarium show. She did note that there were some observations of students with decreased astronomy knowledge when a planetarium show was combined with both pre- and post-classroom learning, which she attributed to content fatigue. Despite this, Sarrazine (2005) does demonstrate that mixing planetarium and classroom learning is effective in teaching students astronomy.

Sunal (1973) and Ridky (1974) showed that a visit to the planetarium, when combined with classroom instruction could offer a chance for students to more fully describe concepts of celestial motion. However, the planetaria used in these studies were situated within the formal learning environments of schools themselves. Thus it was easier for teachers to take their students to the planetarium for an extended period of time, with less disruption to the school day, on multiple occasions as Sunal (1976) suggested. These types of planetaria are not available to all school districts and have been waning areas of the United States in numbers in recent years due to budget cuts. Thus, it is more and more likely planetarium visits will have to occur at museums and other informal learning environments through single planetarium field trips or portable domes, where affective goals are held to the same regard are formal content learning goals (Kisiel, 2005; National Research Council, 2009, 2010; Small & Plummer, 2010). It is important to consider and study how to effectively use planetaria for field trips and as informal environments.

Unlike Ridky (1974) and Sunal (1973), Sarrazine (2005) did test and show positive results for field trips to planetaria. This work only focused on 1-2 lessons tied to the planetarium visit in the classroom before and/or after the field trip in order to test the use of multiple intelligences theory. She was successful in showing multiple intelligences strategies are useful in teaching students astronomy across contexts. She also showed that the sequence of classroom instruction and planetarium visit (either before or after) did not have a significant effect. However, teachers often take their students to informal environments in the middle of extended classroom units (Eshach, 2007; Kisiel, 2005; Lucas, 1998). Sarrazine (2005) did not address how to effectively utilize the planetarium in a more typical and full-fledged unit, where field trips are usually situated.

2.2.3. Summary of Planetarium Learning Research

Research in planetarium learning suggests that they are indeed effective environments that can help students show gains in conceptual and affective domains, particularly when participatory methods are utilized. However, planetarium visits alone are not sufficient if particular learning goals are expected and it is necessary to pair these visits with classroom instruction. Current research on integrating classroom and planetarium instruction has either focused on in-school planetaria that are still components of formal astronomy instruction or has not looked at the role of the planetarium in a complete and extended classroom unit on astronomy. Other research on integrating informal and formal learning can offer insight and is discussed in the next section, along with their implications for planetarium learning.

2.3. Learning Across Contexts

Table 2-1 SMILES Framework

SMILES PRINCIPLE	SMILES GUIDELINES
INTEGRATE SCHOOL AND MUSEUM LEARNING	• Embed the museum visit firmly in a classroom-based learning unit, with the museum visit preferably occurring toward the end of the first half of the unit's program; • Discuss with the students the different learning opportunities offered by the school and museum and how they can best be used to complement each other in the particular topic being investigated; • Plan and prepare with the students the overall concepts to be investigated during the visit; • Consider the students' prior experiences of museums, the particular venue, the topic and the learning approach, when preparing for the visit; • Clarify with the students the purpose and use of students' museum learning particularly indicating how they will use the information at school after the visit.
PROVIDE CONDITIONS FOR SELF-DIRECTED LEARNING	• Foster curiosity by providing opportunities for students to have choice in their specific selection of learning episodes and sites; • Use a learner-centered approach where the students are finding information on their own area of inquiry, within the parameters set by the teacher; • Encourage students to generate questions and use their museum visit to stimulate interest in finding out more about the topic; • Facilitate formation of autonomous groups of students each accompanied by an adult who has been briefed on the program, and/or has some expertise in the topic area; • Facilitate a range of learning approaches and strategies which complement the informal setting and optimize use of all learning opportunities provided • Participate in and model learning in an informal setting.
FACILITATE LEARNING STRATEGIES APPROPRIATE TO THE SETTING	• Provide students with information about the setting – its purpose, content, methods of operating and how displays are prepared; • Discuss with students the learning strategies and opportunities available and the skills required to use them; • Allow a period of orientation at the site; • Anticipate variations in students' concentration and depth of examination of exhibits over the period of the visit. Allow both physical and mental rests.

Many studies on school groups in museums have noted a mismatch between expectations and goals of field trips and the outcomes (Griffin & Symington, 1998; Griffin, 1994; Kisiel, 2003b; Ramey-Gassert et al., 1994; T. Tal & Steiner, 2006). The SMILES framework offers overarching principles and specific guidelines on how to build cross-contextual curriculum to combat this mismatch (Griffin, 1998). The SMILES framework was developed based on extensive research on informal learning, iterative tests of initial versions of the framework, and various learning theories including constructivist, socio-cultural, and situated cognition traditions (Griffin, 1998). Since the SMILES framework serves as a focus for the research questions and the primary basis for the curriculum designed for this dissertation, it will act as a frame for discussing the relevant literature on integrating informal and formal learning.

In the following sections, each of the three main principles of SMILES will be introduced along with a discussion on the relevant learning theories and other studies that have been conducted and how they support the principle. This will include studies that have come out since SMILES was developed. The relevance to planetarium learning expected changes to the framework for use with planetaria will be discussed at the end of each section. A summary of the SMILES principles and guidelines are summarized in Table 2-1 (pg. 21). It should also be noted that the research and theories discussed can and do traverse the principles and guidelines. What is presented is simply one way that we can organize them.

2.3.1. Integrating School and Museum Learning

This first principle deals primarily with providing supports and structure for students to learn across the classroom and museum settings (Griffin, 1998). Its guidelines address preparing students for the types of concepts they will see during the visit, considering students' differing backgrounds and prior knowledge, making sure students are aware of the affordances of each learning environment, and of the purpose of the visit. Learning theories surrounding the contextual dependence on learning and the importance of prior knowledge contribute to understanding and supporting this principle and are discussed below. Additionally, previous studies that demonstrate the importance of providing students with structure and purpose will be introduced before discussing the guidelines and their relevance to planetarium field trips.

Contextual Dependence on Learning

The contextual model of learning states there are primarily three contexts centered on individual learners: personal, socio-cultural, and physical (Falk & Dierking, 2000; Falk et al., 2006; Falk & Storksdieck, 2005). The personal context explains that all learning is filtered first through each individual's unique prior history, motivations, and choices in learning episodes. The sociocultural context includes the social interactions that people have, such as the group they visit a museum with and their effects on how and what they learn. Finally, the physical context accounts for how space and preparation might affect how visitors move or feel during learning episodes. All of these factors come together to affect how a person learns and engages during a museum visit.

These more individual contexts of Falk and Dierking (2000) may need to be supported differently depending on the overall environment a learner is in and knowledge is firmly situated and inseparable from the larger context in which it is learned (Anderson, Reder, & Simon, 1996; Brown et al., 1989; Palincsar, 1989). For instance, many people are able to easily conduct math using fractions and percentages while shopping in a supermarket, but not necessarily do similar but more abstract problems in a formal settings (Bransford, Brown, & Cocking, 2000). The contexts where one learns can influence the type of language, tools, and modes of communication people might use (Bransford et al., 2000; Brown et al., 1989; Palincsar, 1989). The community of practice or culture in which someone learns can also influence aspects of a person's identity and understanding of what is successful and acceptable (Lave & Wenger, 1991). Due to this dependence on a context, it can be difficult for students to transfer and abstract knowledge in such a way that is useful and applicable in other situations (Bransford et al., 2000).

Learning in formal classroom settings tends to be more structured, sequenced, teacher-centered, competitive, and goals-driven while informal learning tends to be more collaborative, open-ended, unstructured, and learner-centered (Wellington, 1990). The goals of informal education often include those that are more affective in nature such as sparking interest and excitement, while formal education puts a greater emphasis on reaching specific learning goals (Hein, 1995, 2006; National Research Council, 2007, 2009, 2010). Museums also tend to be big, imposing, and filled with interactive exhibits and rare and unusual artifacts where some inspire reverence and others support play and exploration (Cameron, 1971; Gurian, 2006; Gurian, 1999; Hein, 2000). These differences in goals, expectations, and even physical space mean that the contexts in which students learn in a formal environment can be markedly different from an informal learning environment.

As discussed in the previous chapter, there are a number of advantages and reasons to take students on field trips to informal environments. Thus we need to support students in transferring knowledge between the two different contexts. However, that support is likely most useful when students are explicitly told to make connections and there at least some abstract similarities between the contexts (Gick & Holyoak, 1980). Therefore, we need to be able to provide students with explicitly relevant activities in the classroom before and after a visit to support this transfer of knowledge across formal and informal contexts. As a result it is important that students are supported in learning across settings in a way that is consistent across the informal and formal settings.

Prior Knowledge

An important aspect to the personal context is that students are filtering their new knowledge through existing knowledge and experiences (John H. Falk & Dierking, 2000). This stems from constructivist theories of learning that state students come in with prior knowledge of content areas based on personal experiences and instruction from which they construct and revise knowledge (Piaget, 1970). Students' prior knowledge can act both as a help and hindrance when learning new information in any context (Roschelle, 2007). Students may need a certain requisite knowledge in order to construct certain normative concepts. For instance, for students to understand how lunar phases work, they first need to know that the moon orbits the Earth. However, their own initial ideas could cause them to interpret information differently than intended. For example, students may try to reconcile their belief in a flat earth and the idea the Earth is spherical to mean we live on flat ground inside a partially hollow sphere (Vosniadou & Brewer, 1992). There needs to be some pre-activities prior to visiting a museum that appropriately prepare students for the concepts that they may visit while on a field trip. They either need to be given some requisite knowledge, or be reminded of and activate previous knowledge they have already gained as a form of preparation.

These ideas may be naïve and intuitive which can lead to misconceptions that may be difficult to change (Gopnik & Wellman, 1992; Minstrell, 1989; Posner, Strike, Hewson, & Getzog, 1982; Smith, diSessa, & Roschelle, 1993). Student's ideas are very personal, incoherent, and stable (Driver, 1985). This means students may hold onto their ideas in a way that may only make sense to them. They may not initially see any inconsistencies in their explanations of phenomena. Thus, students need multiple exposures to the same idea across contexts before it becomes normative and concrete (Bransford & Schwartz, 1999; Minstrell, 1989; Posner et al., 1982). In addition to pre-activities, post-activities will further help learning by giving students more exposure to similar ideas they found in the museum.

Other Studies and the Importance of Purpose

The contextual nature of learning and importance of prior knowledge suggests that including some structured connections between the informal and formal context can help students make the most out of their field trips. There have been a few studies that have looked specifically at incorporating pre- and post-activities into school visits to science centers and their effects on student learning and attitude.

Orion and Hofstein (1994) conducted a study with 296 9^{th}-11^{th} graders from 8 different Israeli high schools by collecting attitudinal and achievement questionnaire data, observations of students groups, interviews with students and teachers, and self-report data. Data was collected before, during, and after a field trip to a geological site. Teachers were interviewed into order to determine the level of preparation students had 3 areas including the concepts they would be encountering, the physical space of the field trip, and the agenda for the day. Level of preparation included receiving information in all three areas, only conceptual preparation, or no preparation at all. The results indicated that the classes that had preparation in all three areas showed more significant gains in their knowledge and attitudes than those students that were less prepared.

Anderson et al. (2000) studied the use of post-visit activities by reporting on 2 case studies of 11-12 year-old Australian students. Concept maps, audio-visual-recordings, worksheets and interviews were collected before, during, and after a field trip to a science center to study electricity and magnetism. Post-visit activities for the students included a review of what they learned from key exhibits and related experiments. The results suggested that students were able to modify and call-upon their knowledge from museums in post-activities. The post-activities helped students further develop ideas and reveal new alternative ideas that could help make teachers detect and thus further help students toward normative ideas. Additionally, Anderson et al. (2000) noted that especially in the 2 students reported, there was a heavy reliance on prior knowledge and experience that helped students further construct their ideas throughout the visit and post-visit activities. This shows the importance of preparing students conceptually as well continuing exposure after the visit.

Lucas (1998) conducted a case study of a teacher in Australia and how she reached her agenda for a science center visit through pre- and post-activities. Colleagues and staff at the museum described the teacher as exemplary. She stated she wanted her students to learn something from the visit and have fun. To help prepare students, she created a “mini-museum” in the classroom prior to the visit discuss with students her plans and expectations. Lucas (1998) noted that this created a similar environment as the museum and effectively bridged the learning across settings as students adopted the teacher’s agenda and purpose for the visit. After the visit students reflected on what they learned and how it was relevant to their everyday life. The students enthusiastically discussed the visit with their teacher and showed that they had gathered some correct knowledge they revisited. Students also reflected and generally agreed they had fun while on the visit. This study suggests that ample preparation, particularly that which offers purpose, supports students to address the differences and make connections across those different contexts.

DeWitt and Osborne (2007) also conducted a small exploratory design study to test their Framework for Museum Practice. They studied field notes and observations of students looking for behaviors consistent with their 4 principles of the Framework for Museum Practice, one of which included providing structure through pre- and post-activities. The study revealed many instances of students making explicit connections in their visit to pre and post-activities. They used their visit to further think about and discuss their ideas. They also interviewed the teachers they worked with in order to gather insight. Teachers noted that the clear purpose of the visit for the students and providing structure seemed to help them students to engage more fully while at the museum.

These studies highlight the importance and usefulness of specifically using pre-activities to prepare students for the visit and post-activities to help continue learning after a visit to a museum. With pre-activities, students are able to gain prior knowledge necessary to help them learn in the informal environments. Similarly the post-activities help students reflect on what they learned and allow extra exposure to more appropriately apply that knowledge.

Another major theme across the studies is that preparing students specifically for the purpose of the visit is also helpful. If students know and share a purpose, as in the Lucas (1998) and DeWitt and Osbourne (2007) studies, students may be able to gain more from the experience and it acts as another form of preparation to transfer knowledge across contexts. Griffin (1998) notes as part of her initial studies in developing SMILES that students who had a distinct purpose for their visit were more engaged than student who did not. One student she interviewed specifically stated, "it needs to have something to do with school so we can relate what we're seeing here to what we're doing at school" (Griffin, 1998, pg. 96). If students do not know or understand the purpose, they may not be able to make the connections and reach the goals the teacher expects.

Principle 1 Guidelines

The guidelines of principle 1 address the contextual differences across settings, the importance of prior knowledge, and purpose. First, we need to "embed the museum visit firmly in a classroom-based learning unit, with the museum visit preferably occurring toward the end of the first half of the unit's program" in order to make sure that the visit is not completely disconnected from what students are learning. This could include pre- and post-activities that explicitly connect the visits together so students can transfer relevant information and knowledge. Griffin (1998) also noted in her trials that students were able to engage more and found more relevance when the visit was toward the end of the first half of the unit. This is because students had the right amount of prior knowledge to help them understand and learn at the museum, but not so much that they found the information irrelevant and boring.

Preparation also needs to go beyond the existence of similarly crafted activities across settings. It is also important to make students aware of more specific differences in those contexts and why they are visiting the museum. The guideline "clarify with the students the purpose and use of students' museum learning particularly indicating how they will use the information at school after the visit" explicitly mentions the importance of making students aware of why they are visiting and to explicitly tell them to make connections. The guideline "discuss with the students the different learning opportunities offered by the school and museum and how they can best be used to complement each other in the particular topic being investigated" complements this guideline by makings sure students are also aware that the museum is different in terms of learning context, but those differences are useful for their unit.

The SMILES guidelines "plan and prepare with the students the overall concepts to be investigated during the visit" and "consider the students prior experiences of museums, the particular venue, the topic and the learning approach, when preparing for the visit" addresses the importance of making sure students have the requisite prior knowledge while also considering what they already know. Students will need preparation for the types of concepts they will be seeing. If they are introduced to in the context of the classroom and the museum it may also help with issues of transfer across contexts as well as helping them find ways of fitting new information into their existing mental models.

Relevance to Planetaria and Expected Outcomes of Principle 1

Students are learning spatially difficult concepts in a planetarium over a short period of time and they will likely not develop deep understanding in a single planetarium show (Lelliot, 2007; Plummer, 2007). Furthermore, they will be in a different context from the classroom physically and with a different way of observing than they may be used to. Within astronomy, there are number of misconceptions students hold about objects in the sky (Nussbaum, 1985; Plummer, 2007; Starakis & Halkia, 2010; Vosniadou & Brewer, 1992, 1994). These factors suggest that integrated pre- and post-activities tied to the planetarium show can be built to directly address the most commonly held non-normative ideas before they even visit the museum. Students may also be able to focus on more salient points during a show if they are given a purpose for what they are supposed to learn there. This aspect of the principle will also be easily implemented with planetaria and there will likely be minor modifications, if any.

2.3.2. Providing Conditions for Self-Directed Learning

The second principle of SMILES deals primarily with providing conditions for a learner-centered environment while at the museum. The guidelines offer means of supporting students with some choice and control in what, how, and with whom they learn. Allowing these types of conditions can support student motivation and interest in ways that get them excited for the visit, but also extend back into the classroom. The principle recognizes the social aspects of learning noting that people learn through interactions and conversations with others. Teachers also play an important role in this social interaction by facilitating different modes of learning and modeling how to learn across contexts.

Importance of Choice and Control

As discussed earlier, people learn partially within a personal context driven by their own history and prior knowledge (Falk & Dierking, 2000). An important aspect of this context is allowing visitors at a museum to have choice and control in their learning according to their own interest, motivations, and curiosity (Falk & Storksdieck, 2005). This has been shown to have positive effects in learning in the informal environments and can potentially help stimulate further student interest in a topic (Griffin, 1998). However, choice and control are important factors in student learning and motivation to learn in any setting and could potentially support learning across the contexts for extended periods of time.

It has been shown that if students are given some level of choice in the classroom they are more likely to be cognitively engaged and show positive affect regarding learning (Hidi, 2000). For instance, Cordova and Lepper (1996) studied students in various conditions of a computer based curriculum, where some groups were allowed choice in aspects of the curriculum. They studied affective and content outcomes through the use of Likert surveys and pre/post-tests respectively. They found that even though the students did not choose the topic they learned about, those given some choice within that curriculum were more deeply engaged and more intrinsically motivated to learn. Additionally, students showed higher gains in both self-competence and amount they learned during the curriculum.

Choice, control, and feeling of autonomy in one's learning is also directly tied to intrinsic motivation and student gains in interest (Cordova & Lepper, 1996; Falk & Dierking, 2000; Lepper & Henderlong, 2000). Intrinsic motivation in turn has been linked to mastery performance goals in students, meaning they wish to fully understand and comprehend a subject (Schunk, Pintrich, & Meece, 1996). Students that adopt a mastery performance goal are more deeply engaged with materials, study for the sake of understanding, and engaged more thoroughly in meta-cognitive and self-regulation strategies. This is opposed to performance learning goals where students try to best others and are driven by their own ego (Schunk et al., 1996). Students with this goal orientation also show more focus on surface level engagement, such as memorization of facts, and have less retention of knowledge (Pintrich et al., 1993). Since choice, intrinsic motivation, and mastery goal orientation are linked, allowing choice in learning episodes is recommended as one strategy to promote mastery goal orientations and intrinsic motivations of students in classrooms (Schunk et al., 1996).

The work discussed above suggests that choice can have positive effects on student learning, engagement, and feelings toward learning. Museums in particular are characterized by their free-choice nature and are thus very adept to supporting visitors as they explore according to their own choices (Falk et al., 2006). When visitors, including students, are asked about their museum experience, they state choice and control as something they value and appreciate (Griffin & Symington, 1998; Griffin, 1998; Kisiel, 2003b). Thus, museums can easily exploit the benefits of student choice, which can result in more motivation to learn later on in the classroom.

The open-ended nature of museum learning, however, needs to be tempered when paired with formal learning goals. Choice must be within constraints of a specific topic area determined by a teacher to help students meet state and national standards and prevent off-task behavior (Cordova & Lepper, 1996; Kisiel, 2005; Lepper & Henderlong, 2000). Bamberger and Tal (2007) studied the effect of difference levels of choice on students learning by observing, interviewing, and collecting worksheets from 750 6^{th}-8^{th} graders in Israel. Level of choice included no-choice, free-choice, or limited choice where students could choose time spent, order, and which exhibits to visit within some constraints placed by the teacher. Student task behavior, ability to connect the museum experience to prior knowledge, school curriculum, and prior life experiences were studied as a measure of learning. The results showed that students in the limited choice conditions were more deeply engaged while at the museum because it was able to balance between giving students control in their learning with offering some support and scaffolds that guided that learning.

There has also been extensive work on students using worksheets in museums. Students have stated that they prefer when they are given choice in what they do and learn at a museum and worksheets are cumbersome and limit that control (Griffin & Symington, 1998; Kisiel, 2003b). Mortensen and Smart (2007) studied the use of worksheets designed specifically to address choice and control in museum settings. They looked at conversations and behaviors to search for evidence of learning with 47 groups of 3rd-5th graders as they visited a natural science museum in North Carolina. Of those groups, 24 were given a worksheet that offered choice in subject and exhibit the students visited with a chaperone or by allowing multiple correct answers for open-ended questions. The remaining 23 were a control group with no worksheet. The results showed that students in the intervention condition with a free-choice worksheet focused on specific curriculum displayed more behaviors and conversations that suggested they were engaged and learned information related to the curriculum. This suggests that allowing choice in worksheets can be useful and beneficial in helping students gather useful information from a museum. Worksheets also offer some level of structure that helps focus students within a topic to also support their learning in a way consistent with what teachers need students to learn.

This research suggests that giving students, choice, control, and autonomy in how they learn is essential. However, there may be a need to limit that choice to support students when learning in the museum environment. Students with no-choice could easily become bored and lose interest, while students with completely free-choice may not know what to pay attention to and similarly get off-task (Bamberger & Tal, 2007; Griffin & Symington, 1998; Kisiel, 2003).

Social Nature of Learning

Some guidelines in this principle stem from socio-constructivist views on learning, which state that knowledge construction is social in nature (Lave & Wenger, 1991; Vygotsky, 1978; Wertsch, 1985). This means, learning begins outside of the child through observation and interaction with other people such caregivers, teachers, or other children. Over time the child internalizes what is seen to use that knowledge later (John-Steiner & Mahn, 1996; Vygotsky, 1978). These social interactions do not stand alone, but are mediated and influenced by culturally constructed tools and, to a large extent, speech and language that the child can use to further communicate and internalize knowledge (John-Steiner & Mahn, 1996; Schauble et al., 1997; Vygotsky, 1978).

As mentioned earlier, Falk and Dierking (2000) discuss something similar in the contextual model of learning by noting there is a sociocultural context in which people learn. On a larger scale, people interact within the culture they belong and their own past can affect how they learn and what they learn at the museum. On a smaller scale, this context means people will interact with a variety of others as they make meaning at museums (Falk & Dierking, 2000; Falk et al., 2006; Falk & Storksdieck, 2005). This includes people within their immediate social group including peers, family members, and teachers as well as those outside the group including other visitors, docents, and presenters.

The importance of language and interaction with others has prompted studies on visitor social interaction, collaboration, and conversation that have shown evidence of visitors learning with others in museums. For instance, Crowley and Callanan (1998) studied parent/child interactions at a children's museum in California. They coded for types of child behavior regarding an exhibit on a zoetrope (a series of images on a rotating cylinder viewed through slits to give the appearance of motion) as well as the types of explanations parents offered. They found that children who interacted with their parents engaged with the exhibit longer, explored more aspects of the exhibit, and talked more about the exhibits. Crowley and Callanan (1998) explain that this social interaction with parents enriches the child's set of experiences they can then draw upon to construct their knowledge.

Allen (2002) also studied interactions between visitors, focusing on conversations between 49 pairs of visitors, including both adult/child and adult/adult grouping, as they explored an exhibit on frogs at the Exploratorium in San Francisco. She coded expressions and episodes of conversation for possible evidence of learning or at least a process associated with learning in some way based on sociocultural literature. Her code categories included perceptual (e.g. factual statement about exhibit), conceptual (e.g. prediction, metacognition), connection to other experiences ore exhibits, strategic (e.g. how to interact with the exhibit), and affective (e.g. intrigue/surprise, pleasure). She found that pairs spent on average 83% of their stops at exhibits engaged in some kind of talk that could be connected to learning, which a majority of these instances categorized as perceptual, affective, and conceptual. Only 3% of their time engaged in completely irrelevant conversation and 14% of their time in silence.

Piqueras et al. (2008) similarly studied the conversation of 3 student teachers as they looked at a diorama showing the competition between crows and vultures at a natural history museum in Sweden. They transcribed and coded conversations for connections between information they had and filling in gaps in the their knowledge. The conversations showed several instances of the student teachers noting gaps in their knowledge and suggesting answers based on their observations. These were considered moments that changed the direction of the conversation toward other questions with an ultimate results of the students coming to biologically sound ideas regarding the diets of the birds.

Socio-cultural constructivism recognizes that there are inherent social processes involved in learning and meaning making. As Smagorinsky (2007) discusses, the fact that learning is situated in social interactions does not automatically suggest that supporting group work in learning in necessary. The work in museum learning does suggest that promoting group learning can be very beneficial. These studies suggest that promoting situations where students can interact with one another, work together, and discuss what they are seeing can be helpful for learning in the museum setting.

There are also other aspects of sociocultural theory can support group learning as well, in any context and not just the museum. Vytgotsky suggested that students have a Zone of Proximal Development (ZPD), described as the difference between what a student already knows and what they could potentially understand with help (Vygotsky, 1978; Wertsch, 1985). Students can reach that potential through social interaction with peers, which suggests allowing students to work together in some capacity will be beneficial to learning. Another important aspect of this is the role of the teacher in facilitating learning. Children learn through imitating and modeling behaviors and actions of adults (Vygotsky, 1978). This is not direct parroting, but something a child can make meaning of and internalize later.

Palincsar and Brown (1984) developed the reciprocal teaching based on ideas of ZPD and the use of expert modeling in apprenticeship situations (Rosenshine & Meister, 1994). Reciprocal teaching was originally designed to support and foster students reading comprehension skills. They would first model comprehension strategies with a student and then allow the student a turn at "teaching". The teacher acts as a co-participant by initially modeling correct behaviors and offering feedback to the child. Eventually, the child is able to internalize more and more of the strategies and the roles reverse to where the child does not need as much feedback and can perform the strategies by themselves. This suggests that modeling can have a positive effect on teaching students the strategies necessary to learn and has been recommended for science teaching as well (Dell'Olio & Donk, 2007; White & Frederikson, 1998).

Principle 2 Guidelines

The first guideline, "foster curiosity by providing opportunities for students to have choice in their specific selection of learning episodes and sites", recognizes that it is important to address and allow at least some choice in the museum environment to pique students' interest and keep the motivated to learn. A later guideline, "facilitate a range of learning approaches and strategies which complement the informal setting and optimize use of all learning opportunities provided" is added as a means of allowing students not only choice in the physical site, but in how they may collect and interact with information.

Two other guidelines recognize the importance of control and sparking interest in the museum. First, "use a learner-centered approach where the students are finding information on their own area of inquiry, within the parameters set by the teacher", recognizes that students should have some control over what they learn, but it should be limited to some extent by the teacher to help focus student work. The guideline "encourage students to generate questions and use their museum visit to stimulate interest in finding out more about the topic" recognizes the choice is based on personal interest and free-choice learning can also stimulate interest. This guideline offers a concrete suggestion on how students can take that interest back to the classroom through the generation of questions.

The guideline “facilitate formation of autonomous groups of students each accompanied by an adult who has been briefed on the program, and/or has some expertise in the topic area” addresses that facilitation of group work, particularly in museums settings, can be beneficial to learning. The condition of autonomy was also added as Griffin (1998) noted that students enjoyed being able to work with their friends and it allowed students choice and control in their learning episodes, which can facilitate learning as discussed earlier. Finally, Griffin (1998) suggested an adult be assigned to each group in order to allow students more autonomy.

The final guideline, “participate in and model learning in an informal setting”, recognized that teachers can effectively support students in their learning by modeling appropriate strategies, similar to that discussed above with reciprocal teaching. The museum setting is a different context and so the learning episodes may require different learning strategies. For instance, students may need to interact with docents and ask them questions, make observations of animals at a zoo, and discuss what is happening in dioramas. These are all different ways of learning than are uncommon in a classroom. As a result, the teacher can help model those strategies that are most useful in the informal setting.

Relevance to Planetaria and Expected Outcomes of Principle 2

Issues of choice, personal relevance, and social learning are more difficult to address in a planetarium due to the structured nature of the show. First, choice can be difficult to foster within the planetarium, as it is a confined room that is the same show given to whoever attends. Visitors choosing which shows they wish to attend can foster choice to some extent. However, for field trips it is more likely the teacher will be the one deciding. Furthermore, even if students are given some choice through a “voting” scheme that happens before or during the show, there will likely still be some students who do not have their preference chosen, resulting is a lack of control for them.

Social interactions are also limited. For the most part, shows are didactic and lecture-based. Participatory programs that introduce discussion and modeling can be introduced as suggested by Mallon and Bruce (1982) and Plummer (2007), but the interaction is still limited to the student/museum staff level, not with their peers as talking to friends would seem rude. Furthermore, with short shows that often have a lot of ground to cover, allotting time for such interactions may be difficult. Even if time is left at the end of the show, it is possible that not everyone will get their questions answered or they may be too shy to ask in front of a crowd.

This principle is the most difficult to address in this dissertation and will require some modification to the principle guidelines immediately. The guidelines here are geared more toward the museum settings. As a result an initial change will have to address choice and social interaction back in the classroom rather than the planetarium. Since research also suggests that these serve an important role in formal settings, this initial and necessary change will likely have positive results and suggest this modification is positive. Overall, this is the most difficult principle to address and will likely see the most modifications.

2.3.3. Facilitating Learning Strategies Appropriate to the Setting

This principle deals primarily with preparation of students for their visit to the museum. Principle 1 addresses preparing for the purpose and content learned during an excursion. However, the guidelines of this principle focus more on the practical demands and the effects of tangible aspects of the museum. The guidelines address how the novelty of a museum space might affect students' ability to concentrate and possible cognitive and physical fatigue of visiting a museum could elicit.

Novelty Effects

The physical context in which people learn can be directly related to the actual physical space of the museum and how it can affect visitors (Falk & Dierking, 2000; Falk & Storksdieck, 2005).This includes the architecture of a museum, the layout of exhibits and galleries, position and format of labels, size and prominence of the exhibit, and the structure of interactive. All of these factors can influence how long a person decides to stay at an exhibit, their comfort level, what exhibits they focus on (Falk, 1993; Falk, 1997; Hillier & Tzortzi, 2006). These in turn can affect how much and what a person learns and the content a person is able to retain from an exhibit (Falk, 1993; J. Falk & Storksdieck, 2005). Thus, the physical environment needs to be considered before taking students to a museum or other informal space to learn.

In addition to the myriad of factors listed above that can affect learning in informal environments, there is the novelty of the space for students. To some extent, novelty is desired, particularly by teachers, as it can inspire and spark interest in students to see something new (Falk & Storksdieck, 2005; Griffin, 1998; Kisiel, 2005). However, students can become cognitively hampered by the unfamiliarity of museums and thus will not be able to put the effort forward for conceptual understanding (Balling & Falk, 1980; Falk & Storksdieck, 2005; Griffin, 1998). This is one of the most noted effects of the physical environment that can be a detriment to learning.

Balling and Falk (1980) reported on 4 different studies they conducted to test effects of novelty on student learning. I will focus on the two that most directly addressed novelty rather than other mitigating factors such as age and variety of activities. The first study took a homogeneous set of 30 students, where 15 lived near a wooded area while the other 15 lived in a classic urban setting. Students were taken to a wooded area to learn about ecology. The students from the wooded area did significantly better on post-tests showing that the reduction of novelty was less of a barrier to learning.

The second study Balling and Falk (1980) discussed looked at student learning of ecological concepts in their schoolyard, where novelty was low, and in a nature area beyond their community. Students who had visited the nature area before were tested against those who had not. This was partially to also test to see if lack of novelty may have affected students' ability to learn as a result of possible boredom. All students showed significant gains on the activity based at their school, but students who were more familiar with the nature area showed more significant gains than those who had never visited the area before. This again suggests that familiarity with a space reduces the negative affects of novelty.

Though novelty may be able to support students' excitement for a trip, it seems that the main effect is to hinder learning. Students that visit a site prior to the field trip may have better conceptual gains as a result (Balling & Falk, 1980). This has led to suggestions that students should be encouraged visit the field trip site on their own prior to a field trip or visit multiple times during a curriculum (Anderson & Lucas, 1997; Balling & Falk, 1980). However, this is often not possible or practical, especially with funding limits for field trips and it is likely not all parents will be able to take their children outside of school. Griffin (1998) found in her work that offering students orientation to the site prior to the visit through maps, pictures, and descriptions of how the exhibits were made to be useful as students were able to connect what they did back to those discussions. Additionally, Griffin (1998) found positive results from observations and interviews with teachers and student that suggested that allowing students a tour or some orientation period when first arriving at the museum helped reduce novelty and allowed quicker focus on the exhibits.

Anderson and Lucas (1997) more robustly tested the effectiveness of orienting students to the physical aspects of a museum space before going to the museum through the use of content tests after the visit. They studied 3 classes of 8^{th} year students in Australia as they visited a science center. Groups were evenly split into two groups, the first of which received a 40-minute orientation to the science center. This included a description of the building, its history, the types of exhibits they would see, and a map of the floor plan. The remaining students were a control and watched a 40 minutes video on the opening of a different science museum. Anderson and Lucas (1997) found that students in the orientation group showed significantly larger scores on the post-test than those in the control group. This suggests that orientation in the classroom is supportive of learning when time and resources are more limited.

Museum Fatigue

Museum fatigue is a phenomenon noted for almost a century where visitors' attention wanes and they appear to lose interest over time (Davey, 2005). In the literature, museum fatigue is often attributed to mental and physical exhaustion, however there is little direct evidence to back this up (Bitgood, 2009a). Davey (2005) and Bitgood (2009) both argue that there are a number of factors that could contribute to the apparent drop in interest such as the physical design of the exhibit that can lead to competition for a visitor's attention, their choice to change viewing strategies, outside frustrations such as a fussy child, in addition to physical and mental fatigue. However, these are just possibilities and the research so far has not done a good job of using variable control to parse out the exact cause of this apparent drop in attention (Bitgood, 2009a).

Bitgood (2009b) also states that visitors will likely find way to avoid fatigue by either taking breaks or leaving the museum, suggesting that the mental and physical fatigue may not be a huge factor in what is traditionally considered “museum fatigue”. However, this also suggests that actual fatigue can be an important factor, just one that visitors can regulate themselves unlike the physical space and or external frustrations. In school groups, students do not necessarily get this choice to leave or sit down. Therefore it needs to be something explicitly considered as part of the students’ time during a field trip.

Principle 3 Guidelines

The effects of novelty from the physical space and the overall environment are addressed in three of the guidelines for principle 3. The first, “provide students with information about the setting – its purpose, content, methods of operating and how displays are prepared” comes directly for this need to orient students to the novelty of the space. If the space is new to them, they will be overwhelmed and anything to help reduce those feelings will be helpful to learning. The next guideline, “discuss with students the learning strategies and opportunities available and these skills required to use them” addresses the fact that students may not be familiar with how to learn in the physically different environment. For instance student may not know there will be touchscreens with additional information or that they need to find read labels at a museum. Thus, discussing with students strategies before hand helps prepare them for those different modes of learning unique to the physical aspects of the informal site. Finally, “allow a period of orientation at the site” stems from observations made as part of the SMILES study and notes that students may still be overwhelmed once they physically arrive. Allowing students a quick tour to see what is there before settling into deeper engagement with exhibits may further reduce initial novelty.

Griffin (1998) explicitly recognizes that the need for breaks and changes in students’ attention span in her final guideline for principle 3, “anticipate variations in students’ concentration and depth of examination of exhibits over the period of the visit, allow both physical and mental rests." She does not state what those rests need to entail. She noted that students had different cycles of attention and during scheduled breaks for lunch some students did not want stop, others were happy to take a break. To some extent these differences can be addressed through allowing autonomous groups discussed with principle 2, so they can more easily regulate and control their own experience at the museum.

Relevance to Planetarium and Expected Outcomes of Principle 3

Planetaria are very physically immersive areas that can create a realistic recreation of the night sky. The shape of the dome with glittering stars can certainly inspire awe in any visitor. A similar effect as the novelty effect known as the "mystique effect" was reported by Ridky (1975), who noted that people were often too overwhelmed with the planetarium initially to gain significant knowledge and required repeated visits. It is possible this effect may be enhanced with digital planetaria that allow visitors to fly through space in all three dimensions. One solution to this is multiple visits, as Ridky (1975) suggests. This is impractical for many schools that must travel to museums to experience a show. Orienting students to the space through pictures before hand and a description of what they will see may have similar positive reductions of these effects while addressing the resource problem.

Fatigue is not something that has been studied in planetaria. Physical fatigue may not be a large concern as students are sitting most of the time. Though it is not unreasonable to expect students to become mentally fatigued after listening to a lecture for a long period of time or to expect students to lose interest or ability to concentrate. As a result it should be considered during any show given to a school group. Thus, this will be addressed in the design of the planetarium show for this study. It is likely that this principle and these SMILES guidelines may need little to no changes.

2.4. Goals of Science Education

It is increasingly important for adults to be involved in scientific dialogues on national or international levels with issues such as global climate change, alternative fuels, or evolution constantly being a part of policy development, ballot measures, and political campaigns. Even astronomy has frequently been on the national consciousness with plans to send manned missions to Mars, recent budget cuts to NASA, threats from near Earth asteroids, and even falling space junk. Also, the economy is largely driven by careers and innovations in the science, technology, engineering, and mathematics (STEM) fields. This means we need to support and attract students toward these careers to move the nation forward. In order to make informed decisions and entice people toward science careers, students need to be able to learn that science is not just a collection of static facts, but something that is actively done and that they themselves can participate. Science education across the nation needs to cultivate students' ability to productively engage in science whether or not science is a career goal.

To facilitate these overarching goals centered on the active nature of science, it is recommended and expected part of science education that students develop inquiry skills along with content knowledge (American Association for the Advancement of Science, 1993; National Research Council, 1996, 2012). A publication from the National Research Council, the *Framework for K-12 Science Education,* outlines 8 major practices of science that students should be able to do across scientific disciplines: 1) Asking Questions, 2) Developing and Using Models, 3) Planning and Carrying out Investigations, 4) Analyzing and interpreting data, 5) Using mathematics and computational thinking, 6) Constructing explanations, 7) Engaging in argument from evidence, and 8) Obtaining, evaluating, and communicating information. The National Research Council (2012) explains that emphasizing practices can help students develop understanding of scientific content and how science is conducted, its importance in society, and pique students' interest to possibly follow a science-based career path. Though this is geared toward formal education, we can support these practices and conceptions informal settings as well.

The strands of informal science also address the active nature of science and are intertwined goals for students learning science geared toward learning in informal environments (National Research Council, 2009, 2010). Unlike the practices mentioned above, they are more encompassing of not only the skills and practices of science, but of other knowledge and attitudes students should have while learning science. For this reason, they are used in this dissertation as criteria to test the effectiveness of the curriculum built for this dissertation and were used to consider aspects of the study design. It is not unreasonable to use these 6 strands for this study that looks at both informal and formal science learning, as strands 2-5 are adopted from the original four strands of science learning geared toward formal science learning (National Research Council, 2007). Those four strands deal more directly with the scientific practices discussed above and types of knowledge students need. Strands 1 and 6, however, deal with affective goals of science education that are more prominent within informal environments (Eshach, 2007; Tal & Steiner, 2006).

This section will discuss the nature of each strand of informal learning and why it is important to address. It should be noted there are slightly different versions of the strands. The version used in designing this study comes from the National Research Council's publication *Surrounded by Science*, which is more geared toward practitioners such as teachers and museum educators (National Research Council, 2010). Since this dissertation is attempting to modify a set of principles designed for practitioners, I deemed it the more appropriate choice. However, I will draw upon all versions in the following discussion.

2.4.1. Strand 1: Sparking Interest and Excitement

This strand addresses students' emotional engagement with science, which includes sparking their interest, excitement, curiosity, and motivation to learn about a subject (National Research Council, 2009, 2010). An important aspect of this is to support any visitors in becoming life-long learners about a topic or to motivate students to take their newfound interest back to the classroom to continue learning after the field trip. Though it can be a goal to foster interest in formal environments, studies have shown that teachers and museum educators prioritize these affective goals in informal environments and focus on using field trips as a way to spark a sustained interest in a topic (Kisiel, 2005; Lucas, 1998; Tran, 2007).

Perhaps one of the reasons why this is more prominent is that informal environments are more adept at supporting the development of interest. As discussed earlier, museums are environments characterized by the choice and control visitors have in their learning experiences, which is a very supportive of sparking and maintaining interest (Falk & Storksdieck, 2005; Falk & Dierking, 2000; Falk et al., 2006). Informal environments can also give visitors access to experiences that they may never have anywhere else. This includes more interactive and immersive experiences that can help inspire excitement and wonder (Gurian, 2006; Hein, 2000). Museums can offer access to authentic objects that have an "aura" that you cannot experience with any kind of reproduction, causing visitors to feel strong connections to the topic or object and what it means (Benjamin, 1968; Greenblatt, 1991).

Supporting interest and excitement is important, since students engage with tasks differently when they are interested in a topic. If interest is present, students usually engage for longer periods of time, on a deeper level, display mindfulness of the task and associated content, and persevere through difficult tasks (Hidi, 2000; Schunk et al., 1996). Supporting interest in the formal context is important, but the informal environment can best support learning by inspiring that interest and excitement in the first place. The goal of this strand then is to use the informal environment as a motivational tool that traverses the contexts to support further learning back in the classroom.

2.4.2. Strand 2: Understanding Scientific Content and Knowledge

This strand addresses what is perhaps the oldest and most basic goal of science education, helping students gain and use scientific knowledge and content. This includes facts, concepts, models, theories, laws, scientific principles and how these different modes of describing the natural world work together to create the larger understanding of the universe (National Research Council, 2007, 2009, 2010). Another aspect of this strand is also having students gain a concept of how these ideas come about through the gathering and modification of evidence. This involves knowing the arguments and evidence that resulted in this knowledge.

From a constructivist perspective, this goal is helping students build new knowledge or modify their existing knowledge and conceptions to more closely match that of science experts. In the past, science curriculum and content has been structured to focus on students learning facts about the natural world (Kesidou & Roseman, 2002). However, facts alone are not what make up knowledge that experts use on a daily basis. It includes a more complex and integrated understanding of the natural world (National Research Council, 2007). People who do end up following a career in science will need more integrated forms of knowledge as time goes on in order to be successful. Even those people, who do not go into science, need to have a basic understanding of science content in order to decipher news articles and arguments made for policy as those reports stem from science professionals. Additionally, more integrated and complete understandings can also help students reach other goals of science learning such as having the ability to reason about and construct their own arguments related to science content, which is discussed further in the next section (National Research Council, 2007).

2.4.3. Strand 3: Engaging in Scientific Reasoning

Strand 3 deals primarily with students' ability to generate and use scientific evidence (National Research Council, 2010). This includes skills necessary to design and implement scientific investigations such as asking thoughtful questions, making predictions, making conclusions and justifications based on results, reasoning through what the evidence means, and deciding when it is inconclusive (National Research Council, 2007, 2009, 2010). Furthermore, students need to know what kind of evidence needs to be gathered to test ideas and hypotheses and the tools necessary to gather that information.

These skills are tied directly to scientific knowledge (strand 2). A large part of scientific knowledge is not just being able to recite facts and principles, but be able to understand how they interconnect, which requires some level of reasoning and critical thinking skills. Thus, it is hard to separate the two strands. However, this strand looks more specifically at the skills one needs to make those connections and not necessarily making sure students have made the correct links (National Research Council, 2009). Students can still learn skills such as asking questions and designing experiments even if it leads to alternative ideas or are initially incorrect approaches.

This strand of science learning is important as it addresses how students learn. As discussed earlier, students are no longer seen as blank slates where we can just "pour" the knowledge of strand 2 in their minds. Instead, students' unique experiences and interests will filter all of that knowledge (Piaget, 1970; Vygotsky, 1978) and they will construct knowledge in ways that makes the most sense to them. By creating experiments and generating evidence and reasoning through what that means is a vital part of creating or constructing that knowledge (National Research Council, 2009, 2010; Posner et al., 1982).

Beyond just helping students construct knowledge, the skillsets associated with this strand are useful in everyday life as well. People constantly need to take information and evaluate what it means. For instance, when shopping for food or other goods, people are constantly bombarded with claims of healthy snacks, or scientifically proven medications. Similarly, there are political advertisements making claims regarding ballot measures on the environment or healthcare. People need to be able to evaluate the evidence and claims presented to them to make informed decisions.

2.4.4. Strand 4: Reflecting on Science

This strand focuses specifically on students' ideas on the nature of science and the fact that it is something that is actively done. This is not a concept many people understand about science, treating science more as a static collection of authoritative facts (National Research Council, 2007, 2009, 2010). This strand also deals with making people aware of their own views of science and their own processes in learning science.

Other strands of science learning address the active nature of science. Strand 2 includes helping people gain knowledge on how scientific ideas came to be and the process that scientists work through. Strand 3 deals with the processes involved in order to actually collect, use, and argue with data and evidence. Strand 5 (discussed in the next section) addresses the construction of knowledge through social interaction of scientists. However, Sandoval (2005) points out that “doing” science is not necessarily enough to help people know that science is something that is done and may only affect their conception of how their own knowledge is constructed, not the more global and professional basis of scientific knowledge. This strand looks more explicitly at making sure students are overtly aware of the nature of science.

It has been shown in several studies before that students that are more aware of the dynamic nature of science are able to engage with the material more deeply and construct more rigorous experiments, and systematically study topics (National Research Council, 2007; Sandoval, 2005). For instance, Songer and Linn (1991) showed that students that held a more dynamic view of science were more able to describe the relationships between different thermodynamic concepts. Sandoval ad Reiser (2004) also showed students were more able to construct and evaluate scientific explanations when working within a framework designed specifically to support the epistemological aspects of science. Thus, in order to support learning, it is desirable that students have a distinct understanding on the nature of science.

Understanding that science is always adding new things to the public dialogue is crucial for a modern scientifically literate person. People need to understand that scientific knowledge is constantly changing and growing. There are debates on the meaning of results and what is “accepted” truth can change in a relatively short period of time. This is, again, important for understanding policy changes, laws, and ballot measures citizens might be voting on. Without knowledge that science changes, people may not understand the importance of passing certain legislation.

2.4.5. Strand 5: Using Tools and Language of Science

This strand makes sure students understand the there are also social processes involved in conducting science. Globally, science is conducted by groups of scientists who constantly discuss ideas and research through colloquium talks, conferences, and peer reviewed journals. Science is a culture of learning and refinement of empirically derived human knowledge and has a shared set of goals and methods that allow it to move forward. A major aspect of this culture is shared language and tools that scientists have come to accept over time and is also constantly evolving (National Research Council, 2007, 2009, 2010). This contributes to creating the culture of science and more efficiently discussing and sharing ideas.

As discussed in earlier sections, knowledge is situated and depends on the context in which it learned. An aspect of this is the more physical context between the museum and classroom. It also refers to the cultural situation in which someone learns (Brown et al., 1989; Lave & Wenger, 1991). Thus, if we want students to grasp the process and practices of science as well as construct scientific knowledge itself, it is best to help situate them within that culture as authentically as possible. This means we need to make sure students are learning how science is conducted through the use of tools and how scientists talk and communicate with one another about ideas. This will also help people productively participate in the larger scientific discourse surrounding policy and health issues as well as better move into a professional science career.

2.4.6. Strand 6: Identifying with the Scientific Enterprise

This strand addresses students' feelings of being a scientist, meaning their feeling of being able to do and contribute to science in some way (National Research Council, 2009, 2010). This is very closely related to the previous strand as an important aspect of being a part of the scientific culture is feeling like one belongs in that culture. People will not be able to successfully participate within the culture if they do not feel like they belong (Lave & Wenger, 1991).

This is important because helping students feel they are a part of science culture may help them maintain an interest in the topic. Feelings of self-efficacy within a topic can lead to more interest and thus more intrinsic motivation to learn and mastery goal orientations (Lepper & Henderlong, 2000). These in turn lead to deeper engagement with the material and more integrated understandings of scientific phenomena. This engagement and interest could potentially influence their career choice and attract students toward STEM fields. Again, as these fields continue to dominate the economy, it is important to produce and attract talented and interested students to maintain that economy.

2.5. Summary of Literature Review

This chapter outlined several areas of literature that are relevant to this study. First, I discussed previous work in planetarium learning. Planetaria are effective environments that support student learning of astronomical concepts as well as positively boosts their attitudes toward astronomy. However, planetarium visits have been shown to be more effective when they are paired with classroom learning to help students become more exposed to ideas. However, most research on combining planetarium and classroom instruction used in-school planetaria that are dwindling in number or only included one to two additional lessons rather than embedding the visit in an extended curriculum. Thus, there still needs to be research conducted on using planetarium field trips in conjunction with school learning.

I next reviewed literature regarding previous work on integrating informal field trips with classroom curriculum. This section outlined a framework known as the School Museum Integrated Learning Experiences in Science (SMILES) framework, used for integrating museum and classroom science learning and includes specific guidelines on how to create integrated curricula with museums. Many guidelines still have appropriate applications to planetaria such as those that surround the idea of embedding a field trip as part of an extended using by conceptually preparing students for their visit, having a sense of purpose, and making sure students know how the information will be used afterwards stem from conceptions of learning as situated in specific contexts. When learning happens across contexts, such as school and a field trip, students should be supported in transferring that knowledge. Planetaria are rather different contexts than their classroom and thus supporting students for what they will see and do is appropriate. Additionally, guidelines surrounding students fatigue levels and ability to process information in a new space have been shown to exist in the planetarium, thus are still relevant to planetarium learning.

Though several guidelines initially seem appropriate, others do not. SMILES offers several guidelines that state that while in the museum settings, students should be allowed choice, autonomy and the chance to discuss ideas in autonomous groups. These guidelines exploit the motivational affordances of these characteristics of museums. However, these characteristics are more difficult to address in planetarium settings. Offering students choice in planetaria will likely leave some students out and not allow them to see what they want to see. Social learning can be supported, but is limited since shows have strict schedules, Thus it is suggested that these aspects need to be addressed more extensively in the classroom as they are more difficult to address in the planetarium setting.

Finally, the strands of informal learning were discussed. These are the goals of science learning that traverse both informal and formal learning that address the intertwined and multifaceted nature of science including learning of content, attitudinal needs, the social nature of learning. They include making sure that students not only understand content, but the nature of science, how it is a process, collaborative with a shared set of language and tools that scientists use, and that scientists participate in a community of practice. Additionally, students need to be motivated to learn and feel like science is something that is applicable in their lives. If a SMILES based curriculum is able to address all of these goals, then it can be considered “successful” to some extent within this dissertation.

Chapter 3

METHODOLOGY

3.1. Overview

This dissertation is attempting to separate the aspects of museum learning we can apply to planetaria and those that need modification to be more effective within more structured informal environments. To do this, a curriculum on apparent celestial motion was created that incorporated a field trip to a digital planetarium. The design of the curriculum applied the SMILES framework (Griffin, 1998) on how to integrate learning across informal and formal settings and its success was evaluated by finding examples of the 6 strands of informal learning (National Research Council, 2010). This evaluation was done through qualitative and quantitative analysis of surveys, interviews, audio-visual recordings, and student work.

This chapter looks primarily at the data collection and analysis done to answer the first research question:

- **What examples of the 6 strands of informal learning are seen during the implementation of a SMILES-based curriculum that integrates learning across planetarium and classroom contexts?**

In the following sections the location and participants, curriculum design, instrument development, data collection, and data analysis will be discussed and described.

3.2. Locations and Participants

This study was conducted in a 5th grade classroom at a public elementary school in southeast Michigan and a digital planetarium at a local natural history museum. To find participants, 4th and 5th grade teachers that previously brought students to see a show on apparent celestial motion at the digital planetarium were contacted. This grade was chosen because *National Science Education Standards* (National Research Council, 1996), *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993), and *A Framework for K-12 Science Education* (National Research Council, 2012) state that students should be able to describe apparent celestial motion by the end of 5th grade. Mrs. Bishop's class was ultimately chosen from three candidates who responded due to her comfort level with teaching astronomy and her class schedule.

Mrs. Bishop taught a total of 29 5th graders. Students and parents were informed about the study beforehand and given the option to participate in all or part of the data collection. Students who opted out of the study were still allowed to participate in the curriculum. Data in the form of surveys and classwork were collected from a total of N=25 students, while data in the form of audio and video were collected from N=21 students. Students with permission were asked each day if they were confortable being recorded, with one group refusing to be audio-recorded for one day.

The school is in a relatively advantaged neighborhood and only 5% of students eligible for free or reduced lunch compared to an average of 41% of students for the state of Michigan. The school's demographics are 95% Caucasian, 2% Asian/Pacific Islander, 1% Black, 1% American Indian/Alaskan Native, and 1% Hispanic.

3.3. Description of the Curriculum

This section will describe the curriculum designed specifically for this study. First, the design principles and how they worked together are discussed. This is followed by a more detailed description of the curriculum implementation split into a discussion on the classroom environment, pre-activities, planetarium visit, and post-activities. The day-by-day lesson plan can be found in Appendix A.1 (pg. 277).

3.3.1. Curriculum Design Principles

I designed the curriculum specifically for this dissertation project to address integration of planetarium and classroom learning. Since this study is based on testing the SMILES framework (discussed in Chapter 2) for use with planetarium settings, the criteria for most design decisions was to address its guidelines as closely as possible (Griffin, 1998). This led to the overarching structure of the curriculum and the main components, which included pre- and post-activities, the planetarium visit, class discussions, and projects. However, other principles and guidelines were use to address some of the more specific aspects of each component. How SMILES suggested the inclusion of these components is discussed below along with other design principles that informed their development. A chart is shown in Figure 3-1 (pg. 64) to summarize the design of the curriculum. A summary of how the SMILES principles and guidelines were addressed can be found in Table 3-1 (pg. 59).

Pre/Post Activities

Principle 1 of SMILES recognizes the need for cognitive preparation, explicit connections between contexts to promote transfer, and sustained engagement with the topic post-visit. To address this, similar pre- and post-activities were included that addressed the

Table 3-1 Enactment of SMILES guidelines (Griffin, 1998) in curriculum

SMILES Principle	SMILES Guideline	Enactment in Curriculum
INTEGRATE SCHOOL AND MUSEUM LEARNING	• Embed the museum visit firmly in a classroom-based learning unit, with the museum visit preferably occurring toward the end of the first half of the unit's program; • Discuss with the students the different learning opportunities offered by the school and museum and how they can best be used to complement each other in the particular topic being investigated; Plan and prepare with the students the overall concepts to be investigated during the visit; • Consider the students' prior experiences of museums, the particular venue, the topic and the learning approach, when preparing for the visit; • Clarify with the students the purpose and use of students' museum learning particularly indicating how they will use the information at school after the visit.	• The visit occurs on day 7 of a 15 day long implementation • Prior knowledge activated by asking students to predict where the sun will be at different times • Requisite knowledge of directions, altitude, and the sky as a dome introduced • Students are told why they are going to the planetarium and predictions facilitate discussion on planning and expectations for what they will observe • Observations are emphasized to match the observational affordances of a planetarium
PROVIDE CONDITIONS FOR SELF-DIRECTED LEARNING	• Foster curiosity by providing opportunities for students to have choice in their specific selection of learning episodes and sites; • Use a learner-centered approach where the students are finding information on their own area of inquiry, within the parameters set by the teacher; • Encourage students to generate questions and use their museum visit to stimulate interest in finding out more about the topic; • Facilitate formation of autonomous groups of students each accompanied by an adult who has been briefed on the program, and/or has some expertise in the topic area; • Facilitate a range of learning approaches and strategies which complement the informal setting and optimize use of all learning opportunities provided • Participate in and model learning in an informal setting.	• Students are creating predictions and revisiting those predictions afterwards, allowing for self-reflection • Students are applying that knowledge to a question based in the real-world context • Students worked in groups of 2-3 during the entire curriculum • Choice and control is moved to the classroom in the form of an end of unit project where they have some autonomy in how they apply new knowledge
FACILITATE LEARNING STRATEGIES APPROPRIATE TO THE SETTING	• Provide students with information about the setting – its purpose, content, methods of operating and how displays are prepared; • Discuss with students the learning strategies and opportunities available and the skills required to use them; • Allow a period of orientation at the site; • Anticipate variations in students' concentration and depth of examination of exhibits over the period of the visit. Allow both physical and mental rests.	• Novelty is reduced by explaining what the planetarium does • Students engage in similar pre- and post- activities to address the structured nature of planetarium • Data collection is similar across the contexts • End of the planetarium show was on mildly unrelated content • Students discussed strategies on remembering information

Table 3-2 Michigan GLCES and derived learning performances used in development of curriculum content

<u>Content Standards</u> **E.ST.04.11** Identify the sun and moon as common objects in the sky. **E.ST.04.24** Explain how the visible shape of the moon follows a predictable cycle, which takes approximately one month. **E.ST.04.25** Describe the apparent movement of the sun and moon across the sky through day/night and the seasons.
<u>Inquiry Standards</u> **S.IP.04.11** Make purposeful observation of the natural world using the appropriate senses.
<u>Learning Performances</u> • Using recorded observations students will be able to describe the motion of the sun through the sky as a continuous arc from east to west • Using recorded observations, students will able to describe that the sun's rise and set positions moves toward north in summer and toward south in the winter • Using recorded observations students will able to describe the motion of the moon through the sky as a continuous arc from east to west • Using recorded observations students will be able to describe that the moon slowly changes apparent shape in the sky and cycles through those shapes every 28 days.

specific content students would see at the planetarium. In addition to simply being similar, principle 1 suggests that students need to have purpose for their visit to the informal environment. So the pre/post activities were also designed specifically to introduce this purpose, discussed further in later sections.

Michigan State Grade Level Content Expectations in Science (GLCES) were used to determine the specific nature and content of the pre/post activities. GLCES include standards for content as well as science inquiry skills. GLCES, including the inquiry standards, were used over national standards because teachers in Michigan need to make sure their students can demonstrate that particular set of knowledge and skills on state mandated standardized tests. The national standards GLCES are, however, very similar in content. This addresses the needs and possible concerns Mrs. Bishop may have had in making sure she taught content relevant to the standards, as recommended in the Framework for Museum Practice (DeWitt & Osbourne, 2007). The standards for apparent celestial motion and observational inquiry skills were used, as they are best suited to the affordances of the planetarium.

To further help guide what the pre- and post-activities looked like, learning performances were derived from the content and inquiry standards used (Krajcik, McNeill, & Reiser, 2008). This lead to having students make observations of the apparent motion of the sun and moon at the planetarium as a means of testing predictions, offering purpose to the visit. The exact content and inquiry standards chosen are outlined above in Table 3-2 along with the generated learning performances. It should also be noted that these are 4th grade GLCES but the students did not learn this material until 5th grade at their school.

Planetarium Visit

Principle 3 of SMILES recommends considering students' attention span while at a museum, thus the planetarium show did end with a tour of constellations up that night and flying to the planets to see them up close, which was not directly relate to the curriculum. Additionally, SMILES principle 3 states students need a period of orientation at a museum. To address this, students were oriented to the directions, horizon, and zenith in the dome upon starting the show.

The GLCES and learning performances discussed above were used to determine the exact content of the planetarium show and make sure it focused on observing phenomena that could be seen in the actual sky. This included having the students observe the apparent motion of the sun and moon, and observe the moon through and entire month to see how its phase changed.

Additionally, previous research has suggested that participatory planetarium shows are more effective at helping students learn content and gain positive attitudes toward astronomy (Mallon & Bruce, 1982; Plummer, 2007). The Kinesthetic Learning Techniques (KLTs) discussed in the previous chapter were used as a means of introducing participatory elements to the show (Plummer, 2007) as they could actively involved students while easily allowing the show to remain on track to address all the content intended across settings.

Projects

Principle 2 addresses students' choice, control, and autonomy as well as the social nature of learning in museum settings. Since choice and social interaction is difficult to foster in planetaria, students worked on projects of their own design and choosing in groups of 2-3 back in school. Aspects of Project-Based Learning (PBL) were used to help structure and connect projects students did after the visit to the whole curriculum. PBL fits in well with the goals and guidelines of SMILES as it similarly stems from a constructivist and situated cognition approach and is meant to have students explore their own questions and ideas in groups within a topic chosen by the teacher (Krajcik & Blumenfeld, 2006). Not all features of PBL were addressed to the same degree due to time and resource constraints.

PBL has 5 major features: 1) a focusing, open-ended, real-world, driving question, 2) learning situated in authentic science activities such as developing plans for investigation and writing explanations, 3) Collaboration amongst students 4) Using technology tools, and 5) creation of artifacts (Krajcik & Blumenfeld, 2006). The driving question in this curriculum was ***"How can we use the sun and moon to tell time?"*** It is compelling, relevant, and relates to the GLCES as many pieces of language and tools we use to tell time derive from how the sun and moon behave in the sky (e.g. a.m. and p.m. refer to before and after the sun crosses the meridian). To answer this question, students designed and built devices to tell time using the sun and/or moon. To address feature 2, students wrote out their own set of observations needed to gather information and test predictions that would be used in the design of their device. Students also wrote explanations of their projects and presented their devices to the class. To address feature 3, students worked in groups of two or three where they were free to talk to and collaborate with other groups, allowing a free discourse in the classroom. For feature 4, students were not encouraged or specifically led to technology due to lack of resources, though they were free to explore ideas on their own if they desired. Finally, students created actual time keeping devices they were free to take home to address feature 5. A summary of PBL features and how they were used are in Table 3-3 (pg. 63).

Whole Class Discussion

There were various class discussions students had during the curriculum. First, students discussed the purpose of the visit as advised with SMILES Principle 1. To address the novelty effects students might experience as outlined in Principle 3, discussions about what students would see and how planetaria worked were included. Students also discussed the relevance of astronomy to their everyday life, particularly that of time keeping with astronomy. This was to make sure students were given some idea as to why the driving question was relevant as recommended by PBL (Krajcik & Blumenfeld, 2006).

Table 3-3 How Project-Based Learning (PBL) was enacted in the curriculum

PBL Feature	Enactment in Curriculum
1) Driving Question	• "How can we use the sun and moon to tell time?
2) Situated Learning	• Students wrote out explanations of their projects design and presented it to the class
3) Collaboration	• Students worked in groups and were free to talk to other groups
4) Technology Tools	• Not explicitly enacted, but students were free to find and use their own tools
5) Artifacts	• Students built prototypes to take home

3.3.2. Overview of Classroom Setting

In order to minimize disruption to the students' normal routine, their original schedule of studying science three days in the middle of the week was maintained and they continued using their usual science notebooks to record ideas about astronomy similar to other science units. The curriculum included twelve one-hour science instruction sessions that extended over five weeks plus a 1-day field trip to a planetarium, totaling thirteen hours of instruction. For all activities, students worked in the same groups of two or three, with minor changes on occasion due to absenteeism or behavioral issues. This was to address SMILES guidelines of allowing students to work in autonomous groups. Several students were absent during the third week of the curriculum due to a sudden and severe flu outbreak at the school. Students also had a weeklong winter break after the third week of instruction.

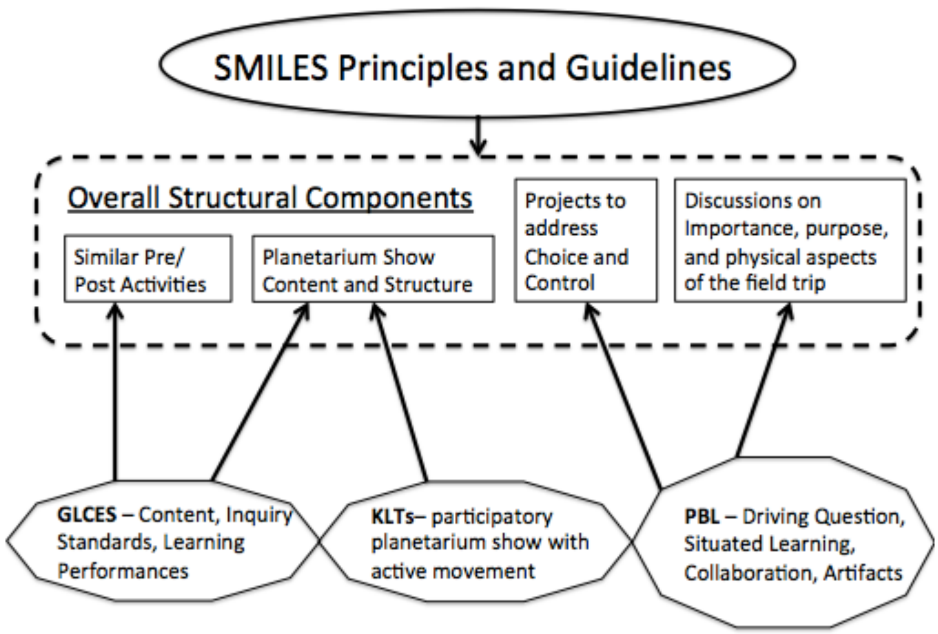


Figure 3-1 Graphical summary of how the curriculum design principles. SMILES contributed to the components of the overall structure, while GLCES, KLTs, and PBL contributed to the specific structure and content of the components. Arrows show what each set of principles informed.

3.3.3. Pre-Visit Activities

Students began by reviewing many key concepts related to the apparent motion of the sun and moon to address a need for conceptual preparation (SMILES principle 1). First, the whole class discussed the concept of the sky as a dome to prepare them for the shape of the planetarium and how the sky is usually modeled. Next, students needed to recognize and describe the positions of objects in the sky to address changing positions of celestial objects. To facilitate this, students were first reminded of the cardinal and ordinal directions. They worked in groups and identified the directions of 8 objects throughout their classroom (handout in Appendix A.2, pg. 281). Pairs of groups switched information they recorded and checked each other's work. The teacher then decided to hold a full class discussion on the importance of using absolute directions as opposed to relative directions such as left and right.

The class then discussed the concept of altitude and how one could describe celestial objects as "high", "middle", and "low" in the sky. During this discussion they were also introduced to the concept of zenith, the point directly over an observer. To practice using altitude descriptions, students were introduced to a diagram where they sky is seen as half dome shaped like window from H.A. Rey's *Constellations* (Figure 3-2, pg. 66). Students went outside, located the sun and recorded the sun's direction and altitude on the diagram. This was done in the morning while the sun was low toward the southeast (example from student work in Figure 3-3, pg. 67).

Using the same diagram, students made predictions for where they thought the sun would be for different times of day, where the sun would rise, its meridian altitude for the first day of each season, and the shape of the moon one, two, three, and four weeks from that day (handout in Appendix A.3. pg. 283). Afterwards, students created lists of observations they would need in order to test those predictions. Students then discussed the feasibility of conducting all of the observations within the limits of the school year. The infeasibility of making those observations introduced the purpose of the planetarium visit as a means of testing all of their predictions in less than a day through direct observation (SMILES principle 1).

The day before they went on the planetarium field trip, students were reminded of the purpose of their visit. They also discussed how they might be able to remember what they saw to prepare them for appropriate learning strategies (SMILES principles 2/3). Since the planetarium was cramped and dark, it would be difficult for the students to record information. As a result, the teacher and students came up with a plan together where each group member was responsible for remembering a certain set of observations so no one had to remember everything. To further prepare students to the physical space, they were also shown pictures of the planetarium, the museum it was housed in, and told how a planetarium works (SMILES Principle 3).

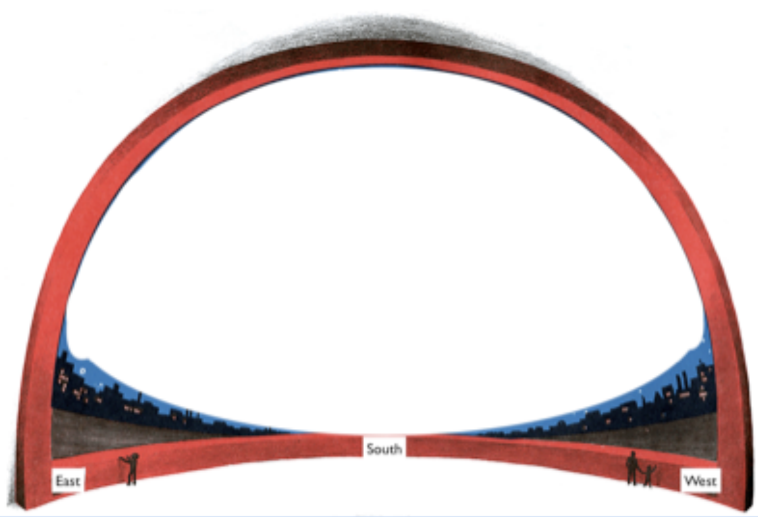


Figure 3-2 Blank sky diagram students used to record positions of the sun and predictions

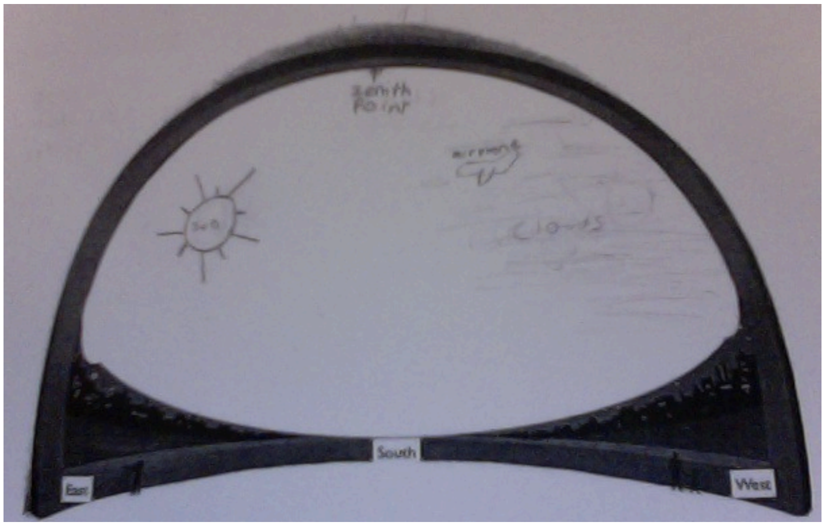


Figure 3-3 A sample of student record of the sun's position. The sun is to the left of the diagram, zenith point is labeled at the top, a plane is noted in upper right and the far right includes scribbled lines labeled as clouds.

3.3.4. Planetarium Visit

The planetarium show was a modified version of a "Sun, Earth, and Moon" show that already existed at the museum so as not to stray too far from a typical visit. Its structure was changed slightly to match the predictions the students made back in the classroom and to address the idea of using the sun and moon to tell time more explicitly. Due to the modified nature of the show, I presented the show to the students rather than training existing staff[1]. A script of the show can be found in Appendix A.4 (pg. 288).

The show was participatory in nature and adopted kinesthetic learning techniques, both of which have been shown to be effective in planetarium learning (Mallon & Bruce, 1982; Plummer, 2007). Students interacted with the operator during the show by answering questions and raising their hands. They also moved their bodies with the sun and moon's movement during the show to emphasize arc shaped patterns of movement.

[1] I am a trained operator on the digital planetarium and had 7 years experience giving shows to the public and school groups at the time of this study.

The show started with orienting students by having them face north and turn their bodies towards each cardinal direction (SMILES principle 3). Labels for the cardinal and ordinal directions were then turned on in the dome to remind students through the rest of the show. Students were then asked to point to zenith along with the operator. A meridian line was projected that marked altitude in degrees. This was turned on to aid the operator in stopping the sun at its highest point and to emphasize differences in the sun's altitude.

Next, the sun's diurnal motion was shown with students pointing and arcing their arms continually as it moved. The sun's path was shown again, but it was stopped at various points to match the predictions they made during class. These motions were repeated for the first day of each season. Signs were placed at the rise and set positions of the sun during the different seasons to help students keep track of differences. Students were also asked to note the altitude of the sun when it was on the meridian and compare it between seasons.

After observing the sun, the moon's diurnal motion was shown as students pointed and moved their arms to emphasize the arc-shaped path. Then they observed the moon's position relative to the sun starting at new moon with the moon appearing practically on top of the sun. The planetarium sky was moved to sunset and then skipped ahead a day at a time to show the moon's waxing phases and how it appeared to move farther from the sun. Every 3-4 days, the moon's arc motion was shown again. This continued until a full moon, where the moon and sun were on opposite sides of the sky. The planetarium sky was then moved to sunrise and the waning phases were shown in a similar fashion, except the moon appeared to move closer to the sun until new moon.

The last 10 minutes of the show was a "star talk" traditionally shown in planetaria. Students were shown constellations that would be up that evening, visited planets up close, and were allowed to ask questions. This was unrelated content to their purpose in the museum, but it is what visitors most commonly expect from shows. Additionally, it helped account for students limited and oscillating attention span in informal environments, as suggested by Griffin (1998) in the SMILES principle 3.

After the show, the students were free to visit other exhibits at the museum. This lasted for approximately 45 minutes while waiting for another 5^{th} grade class from their school to visit the same planetarium show. After their visit, students went back to their classroom and wrote down what they observed at the planetarium in their science notebooks.

3.3.5. Post-Visit Activities

In the next science class (5 days after the planetarium visit), the students made the same predictions they did before the visit. This was meant to help them record what they remembered from the show and compare it to what they originally thought. It also made sure the students had similar activities across settings (SMILES principle 1).

The students were then given a handout where they ranked pictures of the sun in different positions and the moon in different phases depending on various criteria. These criteria included the time of day, year, length and direction of a shadow the sun cast. These activities were meant to help the students think about ways they could use the sun and moon to tell time to support the building of projects and study of the driving question. The full handout can be found in Appendix A.5 (pg. 290).

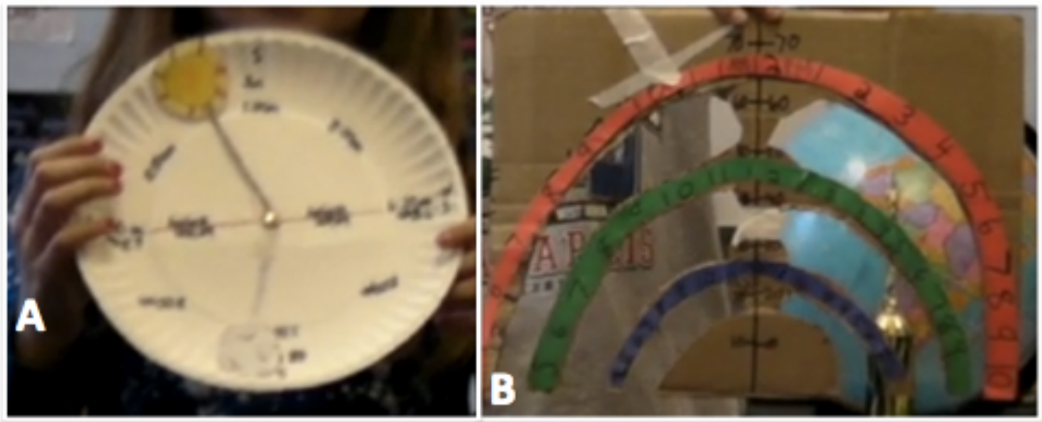


Figure 3-4 Examples of student projects. A) A “clock” where you can move the sun logo (top, tilted left) to match the position of the sun in the sky. The sun lines up with numbers along an arc to tell a rough estimate of the time. Directions are labeled on the horizontal line in the middle of the clock. If you flip it upside down, you can do the same thing with the full moon logo (bottom, tilted left) to tell the time of night. B) A "map" where you hold it up facing south. There are three concentric arcs that are cut out so you can see through it. The arc you can see the sun through tells you the rough season that you are in. The position of the sun in the arc lines up with numbers labeled along each concentric arc. The number with which the sun aligns gives a rough estimate of the time of day. Each arch is color coded for the season.

In order to support student choice, students worked on a project that had them design and build a time-keeping device that answered the driving question “How can I use the sun and moon to tell time?” (SMILES principle 2). Students spent a day discussing with their teacher the types of time you could tell using the sun and moon (e.g. hours, minutes, seconds, weeks, etc.), the history of using the sun and moon to tell time, and situations where they might want to use the sun and moon to tell time to emphasize relevance to their lives. Students worked in groups of 2-3 and brainstormed project ideas for approximately 10 minutes at the end of this class period.

After this initial brainstorming session they had a week off from school. They came back from break and started designing and building their projects over three days in science class. Most groups chose to do a traditional or slightly modified sundial. Many groups created a seasonal “map” of the sun’s position that involved drawing 3 concentric arcs. These worked by lining the sun up with an arc to tell the season, and the position along the arc showed the time of day. Other projects included those where you matched the altitude or rise and set position of the sun to find the date/season. One group of students created a device where you moved the sun to match your observation to get a rough estimate of time on one side and on the other you could match the full moon's position with your observation to get an estimate of the time of night. Some examples of more unique student projects (e.g. not sundials) are show in Figure 3-4 (pg. 70).

Students wrote directions and explanations on how to properly use their devices as well as presented their work to the class. Because many students had similar projects, the teacher decided that all students with sundials, maps, etc. would present together in larger groups so as not to tire everyone out with repeat presentations. Presentations were done to also make sure students participated in other science practices such as presenting and communicating results as suggested by PBL (Krajcik & Blumenfeld, 2006).

3.4. Instruments

This section discusses the development of instruments used in data collection to find examples of the 6 strands of informal learning (National Research Council, 2010). This includes the development of a Likert-style survey and interview protocol used with students.

3.4.1. Survey Development

A survey was used to collect data related to strands 1, 4, and 6. These strands deal with the students' emotional feelings toward the curriculum and their opinions and attitudes toward science, which are easily studied using self-report data (National Research Council, 2009). The survey statements were borrowed from two different commonly used surveys according to relevance to the curriculum and strands of informal learning and then modified to address the astronomy more directly.

The *Science Opinion Survey* (*SOS*) was used in developing questions relating to strand 1 (interest and excitement). *SOS* consists of 30 statements and was originally created for the National Assessment of Education Progress in 1996, used to assess what students know and can do in various subject areas across the United States (Gibson & Chase, 2002). The *Scientific Attitude Inventory - Revised* was used to help develop statements relating to strands 4 and 6. This survey was originally developed in the 1970s and has been used extensively around the world since. It underwent revisions in 1997 for gender bias and addressing more modern views of science literacy (Moore & Foy, 1997). See Appendix B.1, (pg. 294) for the final version given to students.

3.4.2. Interview Protocol Development

An interview protocol to study students' ideas on apparent celestial motion, language use, and justification skills was written based primarily on questions Plummer (2007) used in her study of students ideas across time. She originally used the protocol with N=60 1st, 3rd, and 8th grade students. Her interviews lasted between 10-13 minutes, approximately. She asked students about the apparent motion of the moon, stars, and the sun during the winter and summer. The questions related to the stars were not used, as it was not addressed in this curriculum. A selection of questions relating to the sun and moon are shown in Table 3-4 (pg. 73). Only a selection of sun questions is included as they are very repetitive when asked during different seasons. Her protocol was used as a basis for this study as it addressed many similar questions regarding apparently celestial motion with similarly aged children. The questions were also designed specifically to allow students to express their own ideas, including alternative ideas, and not lead them toward a correct answer (Plummer, 2007). This was useful in studying students' ideas during this study in order to make sure the results were not biased.

The protocol from Plummer (2007) was used as a starting point, but several changes were made for this study. First, the original protocol was used with students under a small dome to allow them to point out their answers in a setting similar to the sky. This was not physically practical as I conducted interviews in a small hallway just outside the classroom. Additionally, this interview was used to study the students' use of astronomy appropriate language. Allowing students a way to answer non-verbally would not have allowed for this.

Language that I used as an interviewer was also modified to ask students to predict answers in order to match activities the students conducted in class. Additionally, the interviews were used to study how the students were able to reason and justify their answers. To address this, they were also asked questions such as "why do you think that?" or "how do you know that?" throughout. The full protocol used in this study can be found in found in Appendix B.2 (pg. 296) and was the same for both pre- and post-interviews.

Table 3-4 Interview protocol samples from Plummer (2007)

Apparent Motion of the Sun	Apparent Motion of the Moon
• What do you like to do during the summer? • Can you show me where the sun is first thing in the morning? • What about a little later in the morning – where is the sun? • Where is the sun at lunchtime? • What is the sun in the afternoon around when school is done? • What happens to the sun at the end of the day? Show me. • Can you show me again how the position of the sun changes? • Point to where the sun will be when it is highest in the sky. • Is that directly overhead?	• Can we ever see the moon during the day? • Where might we see the moon after sunset? • Where is the moon at midnight? • It's still dark out but it's almost time to get up. Where is the moon now? • And where will the moon be when we see the sun again in the morning? • Does the moon always set when the sun comes up? • Where does the moon go when you can't see it? • Show me how the moon changes where it is during the night?

3.5. Data Collection

In this section I will summarize the types of data collected. Each data type was analyzed for examples of different strands of informal learning. How data was analyzed for each strand is discussed in section 3.6 (pg. 79). When data was collected in the sequence of curricular activities can be found in Table 3-5 (pg. 78).

3.5.1. Surveys

A 12-item 5-point Likert survey was collected from N=25 students within a week of completion of the curriculum. There were 4 items each on students' interest and excitement for astronomy and the planetarium visit (strand 1), students' ideas on the process of astronomy (strand 4), and how useful they found astronomy and how they saw themselves using astronomy (strand 6). Again, these are related to students' attitudes toward science and astronomy, which is readily studied through self-report data such as surveys (National Research Council, 2009). The following statements for each strand were in the final version of the survey, with the actual survey administered in Appendix B.1 (pg. 294):

- **Strand 1**
    - I enjoyed the planetarium visit
    - The planetarium visit was interesting
    - I would like to learn more about astronomy
    - I think astronomy is fun
- **Strand 4**
    - It is useful to listen to new ideas in science if everyone does not agree
    - Scientists never finish studying astronomy
    - It is important to make observations in science
    - It is okay if scientists change their ideas about science
- **Strand 6**
    - Only astronomers can understand astronomy
    - Only astronomers use astronomical information
    - I might like to be an astronomer when I grow up
    - I can understand astronomy

In addition to the Likert survey, students were asked to explain their favorite and least favorite part of the curriculum and if they had ever visited a planetarium before. These were asked to contextualize other data as necessary.

3.5.2. Audio and Video Recordings

Audio recordings of museum visitors have been used as a means finding evidence of positive affect (Allen, 2002; National Research Council, 2009). Student were audio and video recorded to study interest and excitement (strand 1) as they worked on their projects. Studying students at this point of the curriculum was chosen because choice and control are connected with motivation, interest, excitement and engagement with the tasks (Falk et al., 2006; National Research Council, 2009, 2010; Ramey-Gassert, 1997) and since choice and control is difficult to accommodate in planetaria it was addressed in the classroom setting through the projects.

The original plan was for students to be recorded anytime they worked on the project. One day of their work was missed due my own family emergency. This day was their last day of active working and most students were just finishing up their last touches. Recordings included audio of when they brainstormed ideas, audio and video of the first 2 days when they most actively designed and built their projects, and the 1-day they gave presentations. Audio was recorded by placing one recorder between the two to three students in 9 groups (N=19 students total) as they worked. These groups were chosen from 21 students that had permission from their parents to be recorded because they were present on the first day of data collection. These groups were kept as consistent as possible, though some groups being studied were merged or split by the teacher due to absenteeism or behavioral problems.

Students were also video-recorded as they worked on the project by placing two cameras in the back of the room that focused on two large tables of students. The first table had 4 groups

(N=8 students) and the other had 6 groups (N=13 students). Video was captured this way due to the limited space in the room for equipment, to avoid recording students who did not have permission, and to give a global sense of what was happening in the classroom. Video's primary use was to track movement of children when they stepped away from their audio-recorder.

In addition to the audio and video collected above, two days of audio and video recordings in a similar set-up from the first half of the curriculum was collected to see what tools students used (strand 5). Tracking data has been used previously in museum settings to study how visitors engage with exhibits (National Research Council, 2009). Similarly, video and audio was used as a means of tracking students to look at what tools they used and how they used them when making predictions, recording the directions of objects, and building their projects.

3.5.3. Interviews

Pre- and post-interviews with students were conducted in order to study students' content knowledge (strand 2), scientific reasoning and justification (strand 3), and language use (strand 5) before and after the curriculum. Interviews with a subset of students were chosen over a written assessment with a larger class for two reasons. First, students tend to talk more than write, ensuring more complete answers. Second, I was able to ask clarifying questions for any ideas they expressed or language they used as necessary.

A total of N=10 students were interviewed in the week before the curriculum started and in the week after the curriculum ended. The students were chosen to be representative of the class as whole in gender and ability level as determined by the teacher. All interviews were recorded and lasted between 9.75 and 23.5 minutes. They were then transcribed by a paid professional and quality checked by me to make sure they were accurate.

The interviews were semi-structured, following the interview protocol as closely as possible and conducted in a conversational tone. Follow-up questions were asked as needed and judged by the interviewer to clarify student statements, word-choice, and ideas. Some questions were modified mid-interview if students appeared to be struggling with a question or asked it to be re-worded. In some cases, questions were omitted if they did not make sense based on previous answers. For example, one student was not asked about the motion of the sun in each individual season after stating clearly she thought it would be the same in every season. At times, the order of the questions were also rearranged if a student started expressing ideas related to a later question to keep the tone more conversational.

Students were also asked to justify their predictions throughout the interview in order to study their reasoning skills (strand 3). It was intended that anytime the student did not spontaneously offer a reason for their answers they would be asked a question that prompted them for a justification. However, I conducted the interviews and did not have much experience prior to this work. In my attempt to keep the tone conversational, I was not as fastidious as intended in asking students to justify their answers, so the same answers were not consistently justified across all those interviewed.

In addition to the transcribed audio recordings, written notes were taken on copies of the protocol during interviews to record hand or arm motions students made regarding the position of the sun or moon. For instance, students frequently arced their arms to describe the sun's motion or pointed to where they thought the sun would be.

Day of Curriculum	Curricular Activity	Data Collected	Number	Duration	Strand Addressed
The week prior to start	N/A	Interviews	N = 10 students	9.75 – 23.5 minutes each, average = 13.8 minutes	2,3,5
1	Introduction	-	-	-	-
2	Coordinate Practice	Audio/Video	N=9 groups	~1 hour	5
3	Predictions	-	-	-	-
4	Prediction Test Design	Student Work on Observation Lists/Protocols	N = 11 groups	-	5
5	Field Trip Preparation	-	-	-	-
6	Planetarium Visit	-	-	-	-
7	Re-Do Predictions	-	-	-	-
8	Ranking Handout	-	-	-	-
9	Project Brainstorm	Audio	N = 9 groups	~10 minutes	1
		WEEK LONG BREAK FROM SCHOOL			-
10	Working on Projects	Audio/Video	N = 9 groups	~1 hour	1,5
11	Working on Projects	Audio/Video	N = 9 groups	~1 hour	1,5
12	Working on Projects	-	-	-	-
13	Presentations	-	-	-	-
Few days after end	N/A	12-question Likert-Survey	N= 25 students	-	1,4,6
~1 week after end	N/A	Interviews	N = 10 students	9.98 – 20.47 minutes each, average = 13.8 minutes	2,3,5

Table 3-5 Summary of data collection in the curricular sequence

3.5.4. Student Work

As discussed earlier, in order to introduce the purpose of the planetarium visit, students created a list of observations they would need to test predictions prior to visiting the planetarium. The ability to construct experiments and proper observational protocols is very important in science. It is also an aspect of reasoning in strand 3 (National Research Council, 2007, 2010). To study how well students were able to construct an observational protocol to test their predictions, their lists of observations were collected. Students worked in groups and produced one list per group. Work was collected from a total of 11 groups that were present and had permission from their parents.

3.6. Analysis by Strand

Here the analysis of the data is presented by strand of informal learning. A mixed-method approach is used to address different data and strands. A summary of data collected and the analysis by strand is found in **Table 3-6** (Pg. 81).

3.6.1. Strand 1: Sparking Interest and Excitement

Likert-scale Surveys

The survey questions for strand 1 were given as a means of gaining a more global and first-hand account of students' interest and excitement in astronomy. The survey had 4 items relating to interest and excitement, and were all worded in a positive manner, meaning agreeing with the statement suggested interest and excitement. Twenty-five student surveys were received, giving a total of 100 answers for this strand. The analysis was done with the aggregate number across all 4 questions in order to relieve bias that might have resulted from the wording or ordering of questions in the survey. The percentage of those 100 total answers for each Likert-scale point was calculated. The results were then plotted in a bar graph in order to highlight any trends in how students answered.

Audio and Video of Students Working on Projects

Mini-case studies were conducted on 4 groups of students to see what their engagement looked like as they worked on their projects. Engagement was studied as a proxy for strand 1, as it has been tied to intrinsic motivation and interest (Hidi, 2000; Renniger, 2000). The term "mini-case study" is used to describe the analysis as only approximately 2 hours of audio and 2 hours of video were used to study this phenomenon per group. Case studies generally use more abundant and diverse data sets that allow for triangulation and expansive deep study than is used here (Patton, 2002).

In order to ensure I found varied examples of what student engagement looked like, I chose the groups through a mix of stratified and intensity sampling from those with complete datasets (Patton, 2002). Complete in this case meant they did not have any recordings missing due to technical glitches, opting out of being recorded for a day, or being unintelligible on the recording. Only 6 of the original 9 groups that were originally recorded had complete data for the time span being studied.

In order to remove some bias I may have had from my experiences in the classroom and with the students, I first stratified the sample. I chose two groups that were more engaged and two groups that were less engaged with the project as determined by their time on- vs. off-task as this has been considered an indicator of engagement to study affect (National Research Council, 2009). I listened to audio recordings and recorded time stamps anytime students changed from being on-task to off-task or vice versa. For periods of silence longer than a minute, I checked video for to see if they were still on-task or off-task. On-task behavior was considered anything relevant to the project (e.g. discussing astronomy content, project materials to use, writing notes in a notebook, cutting out cardboard) while off-task was any activity unrelated to the project that at least half the group was involved in (e.g. dancing, talking about television shows, napping, talking about another school assignment). Normal everyday actions such as getting water or using the restroom were not counted as off-task. Students' time on-task ranged from 73% to 100%.

Table 3-6 Summary of data collection and analysis by strand of informal learning

Strand of Informal Learning	Data Collection	Data Analysis
(1) Sparking Interest and Excitement	● 4 Likert Style questions on interest in science/astronomy ● Video/audio of Final Project work and Presentations (~2 days)	● Percentage of answers per Likert-point ● 4 mini-case studies, Code video that describe student engagement with the project consistent or inconsistent with interest/motivation
(2) Understanding Scientific Content and Knowledge	● Pre and Post interviews with students (N=10) on content knowledge	● Code answers according to level of accuracy, find themes of student ideas within those levels
(3) Engaging in Scientific Reasoning	● Pre and Post interviews with students (N= 10) asking for justified predictions ● Collect student work on their lists for observations they will need to collect to test predictions	● Code predictions for level of justification, use to create 4 vignettes ● Check student lists for level of completeness of observations necessary for testing predictions
(4) Reflecting on Science	● 4 Likert Style questions on science as a process	● Percentage of answers per Likert-point
(5) Using Tools and Language of Science	● Video/Audio of kids doing pre-activities and filling out handouts (~2 days) ● Pre and Post Interviews with students (N=10) that have then describe the positions of objects in the sky	● Find examples of correct or incorrect tool use ● Find examples of student use of 5 key astronomy terms, inductive code for themes of how the term was used and if it was correctly used
(6) Identifying with the scientific Enterprise	● 4 Likert Style questions	● Percentage of answers per Likert-point

I then split the groups into two equal categories: 3 groups that were most on-task and 3 groups that were least on-task. It should be noted that the time on task between 75-90% is considered normal for productive classrooms (Lee, Kelly, & Nyre, 1999). Within this range, four groups are considered normal with one outlier in the low (73%) and one in the high end (100%). However, there could be some errors in the estimations due to students moving to different parts of the classroom that could not be recorded, making it unclear exactly what they were doing.

From this stratification, I chose two groups of students from each category using intensity sampling, where a researcher “seeks excellent or rich examples of the phenomenon of interest, but not highly unusual cases" (Patton, 2002, p. 234) based on his or her judgment and familiarity with the data. In order to familiarize myself with the data, I listened to all of the audio data and watched the video data for each group, documenting what the students were doing and observations on the nature of their engagement. I chose groups that offered a rich set of discussions and activities and varied forms of engagement from each other.

I followed an approach that borrowed from grounded theory where I iteratively analyzed data for these groups inductively at first and then deductively later in order to find patterns and themes regarding their engagement (Patton, 2002). In order to find these patterns, I first described what students were doing. I then used strategies that were appropriate for the small data set, short time frame the data was collected over, and description of engagement. Strategies used included marginal and reflective remarks where I jotted notes and observations next to my descriptions, coding that used short words to categorize what was happening, memo writing where I wrote short summaries of observations, and counting of codes (Miles & Huberman, 1984). These particular strategies also complemented each other nicely as reflective remarks and memos could support the development of a coding scheme (Miles & Huberman, 1984). Counting of codes could be used as a means of testing against my own bias in finding themes.

I listened to the audio of each group and described student engagement for various "episodes". Episodes were distinguished by a change in topic, activity, or with whom the students talked. They lasted between ~5 seconds and ~10 minutes, were on average ~90 seconds, and most lasting ~1 minute. When describing the engagement, I wrote marginal remarks of relevant information or stray observations (Miles & Huberman, 1984). I wrote with multiple codes attached to an episode in some cases. I repeated this for each group and noticed similar codes emerged across groups, though in different combinations. I split codes into

Table 3-7 Final set of codes used to characterize student engagement during projects

Code	Description	*Examples*
Level of Engagement		
SURF	Surface level engagement	*Focusing on how to decorate the project* *Deciding type of glue to use*
DEEP	Deeper level engagement	*Focusing on the functionality of their project* *Making sure they understood how/why their project worked or didn't work*
Activity		
PLAN	Planning how out their project	*Deciding which materials to use* *Making lists of supplies/information to bring in* *Drawing out a design before building*
BUILD	Physically building their project	*Gluing paper to cardboard* *Writing labels* *Drawing/Cutting out shapes*
DISC	Discussing the project	*Sharing new ideas for how they can build the project* *Walking through how their knowledge applies* *Explaining how their project or ideas would work*
ASK	Asking questions	*Asking how something would work* *Asking when the project was due* *Asking about the Milky Way*
PM	Exhibiting "project manager" behavior by telling students what to do	*Telling their partner what to do next* *Telling their partner or other students to stay on task*
ON	Miscellaneous on-task behavior	*Cleaning up* *Talking to the teacher about where to sit*
OFF	Off-task behavior	*Talking to other students about non-astronomy topics* *Talking about another school project*
OOT	Off-topic discussion while doing an on task activity	*Discussing television shows while painting* *Talking about another subject while cutting out cardboard*
Characteristic of Activity		
EASE	Focusing on the ease of the project	*Discussing which project is easier to do* *Telling someone their project is easy*
CURI	Expressing curiosity or interest	*Asking questions about how things work* *Stating random facts about project*
PERS	Persisting or persevering through obstacle	*Sticking up for an idea that a partner is uninterested in* *Finding solutions to problems that arise*
LPERS	Lack of persistence or perseverance	*Giving up with they don't understand something* *Stating frustration when told to fix something*
PRIDE	Expressing pride	*Announcing to everyone their project works* *Stating they really like their project*
GOOD	Desire to do well	*Focusing on accuracy of their work* *Focusing on precision of their project*
FAC	Being factitious/ flippant	*Suggesting unrealistic ideas* *Dismissing a partners idea for being "too smart"*
Who was Involved		
TEA	Another teacher or educator	*Students discussed or asked questions of an educator* *Students made a plan with the help of their teacher*
OTH	Other Students	*Discussing ideas or asking questions of other students* *Helping other students*

different categories that included level of engagement, activity, characteristic of the engagement, and who was involved beyond the group members. From this I developed a final series of codes that I applied to all of the case-study groups to further describe their engagement to deductively verify themes that emerged (Table 3-7, pg. 83). Using counts of those codes along with the memos and marginal remarks, I searched for patterns and themes for each group to describe what their engagement looked like.

Other strategies that were practical to the type of data set were used to further ensure validity of the results. All the data were reviewed multiple times, looking for negative evidence that disconfirmed the themes and patterns noted (Miles & Huberman, 1984; Patton, 2002). All findings and evidence were presented to other education researchers as a form of audience review to credibility of findings (Patton, 2002). In addition to the audio and video data, student survey answers, including answers to their favorite and least favorite part of the unit were used as triangulation sources to confirm or disconfirm any themes that may have arose for each group (Patton, 2002).

3.6.2. Strand 2: Understanding Scientific Content and Knowledge

Interviews

For this strand, pre- and post-interviews with N=10 students were used to study student descriptions and ideas of apparent celestial motion. The interviews covered 3 major topics related to the sun and 3 related to the moon addressed in the curriculum. Sun topics included the diurnal path of the sun, the apparent height of the sun at local noon, and differences in the sun's apparent path between the seasons. The moon topics included the diurnal path of the moon, visibility of the moon during the day, and phases of the moon. Professional transcripts were made of all of the interviews and included pauses (marked as an ellipse), filler words (e.g. um, ah), and notations of other noises (e.g. [*giggling*]).

The interviews were studied to find common levels of accuracy and any common alternative ideas students had before and after the implementation of the curriculum. Student pre-interviews were first read in their entirety for each of the 6 topics. Students were then coded for their level of accuracy in their answer for each content topic according to a rubric shown in Table 3-8 (pg. 86). This table also includes examples of student interview answers for each level when possible. The rubric is based on those used to develop a learning progression for apparent celestial motion (Plummer, 2007), as it addressed many common levels of student accuracy in ideas for apparent celestial motion from N=60 elementary to middle school aged students. It was modified slightly to address all the descriptions students gave across topics addressed in this particular curriculum. For the most common levels of accuracy (those one to two levels where more than 5 students fell) that also showed distinct differences between pre- and post-interviews, I followed an iterative inductive approach to find emergent themes of alternative ideas within those levels and to identify differences between students within each level (Miles & Huberman, 1984). These themes were then tested against all the interviews to see if they were unique to that

Table 3-8 Content rubric (continued onto the next page)

Topic	Level 0	Level 1	Level 2	Level 3	Level 4
Sun's Diurnal Motion	Does not know, says it does not move	Says it moves but does not recognize it as a continual arc motion and does not recognize it as rising in the east and setting in the west	Says it rises in the east and sets in the west and not continual arc motion or vice versa.	Says is does rise in the east and set in the west, and recognizes that it is a continual arc motion, but includes some other inaccuracies, like saying the sun goes toward the North, not South	Says it does rise in the east, set in the west and continual arc motion and says no other mistakes.
Examples	***I don't know*** ***It does not move***	***"In the evening it goes down" [does not include any other information]***	***"…sun rises in the east and sets in the west" [no indication of continual motion]*** ***"…it keeps moving and moving throughout the day…" [but does not know it rises east/sets west]***	***"…rise in the east and go to…the west." [arcing hands] "[at lunchtime]it's north"***	***"…it usually starts somewhere in the east and then it usually goes over and sets somewhere in the west" [arcing hands]***
Sun's Apparent Height	Does not know	Consistently says it's highest point is zenith.	Says it goes through zenith and says it doesn't go through zenith. It could be an inconsistency or it goes through zenith, but only certain times of year.	Says its highest point is less than zenith consistently.	N/A
Example	***I don't know***	***"[the sun] goes all the way to the top"***	***[for fall] "[the sun gets] in the middle, and 50 through 60 degrees…" [but for summer] "[the sun is] right overhead"***	***"…the sun never gets to 90 degrees."***	
Difference in the sun's path through the seasons	Does not know	Describes the paths the same throughout the year or the differences are inaccurate, or many inconsistencies.	Describes the sun's paths as different. Correctly says the altitude is different or rise and set positions different, not both.	Describes the paths as different and continual, with shorter path lengths, different rise positions, and different altitudes, but mixes up the details like saying the summer the sun rises southeast and sets southwest or it moves at different rates.	Describes the paths as different and continual, with different rise and set positions and different altitudes, and has all the details correct

Topic	Level 0	Level 1	Level 2	Level 3	Level 4
Examples	***"I'm no sure"***	***"I think it stays the same the whole year"*** ***"The sun would set still in the west but it would take longer…"***	***"[it rises] the same place…as in the summer" but also says "[the sun is] lower than the summer or the fall"***	***"[the sun is] higher than winter and spring" and "for spring and fall [the sun rises] more to the northeast"***	***[in the*** **summer]"*[the sun] rises in the northeast]" and "[it gets] to the 70-80 point"***
Moon's diurnal motion	Does not know or does not think the moon moves	Describes the moon as moving but not continually and not as rising in the east and setting west.	Says is moves but recognizes it as continually moving or rising east and setting west, not both	Says is does rise in the east and set in the west, and recognizes that it is a continual motion or describes it as moving like the sun	N/A
Examples	***"probably not"***	***"I think it moves when you're sleeping"***	***"[it moves] almost like a crescent shape" but no mention of east to west***	***"It moves like the sun…it would rise in the east and set in the west"***	
Moon visibility during the day	Says it can never be seen during the day	Says yes, but some inaccuracy such as only at certain times of day	Yes, sometimes with no inaccuracies	Yes, and says it depends on phase	N/A
Examples	***It can't be seen***	"***Yes, in the morning"***	***"If it's not cloudy, you can sometimes"***	***"…if it's a little slit, then you might be able to see it in the day"***	
Moon phases	It does not change shape or does not know.	It changes shape, but inaccurate on length of cycle and order of phases	It changes shape, but inaccurate on the order or that it takes about a month to complete the pattern, not both	It does change shape, accurate that it takes a month for a full cycle and the phases are in the correct order	N/A
Examples	***It does not change shape***	***"It goes from a full moon to a crescent…I can't really tell you whether or not it would or not [have a pattern]" and "I don't know [how long it takes]"***	***"…usually stars from a dark moon and…it grows…it's a full moon." And that pattern takes "28 days"*** ***Correct order of phases but says "I think it was two weeks"***	***"It starts out where you can't even see it and then it grows…have a full moon…then it'll come back to new moon" and this happens every "four weeks"***	

accuracy level or if they crossed into other levels as well. This process was then repeated for post-interviews.

3.6.3. Strand 3: Engaging in Scientific Reasoning

Interviews

This strand involves students being able to generate and use evidence (National Research Council, 2009, 2010). The interviews were studied to look specifically at the latter to see how well students were able to justify the answers they gave through appropriate forms of evidence and connecting how that evidence supported their answer.

To analyze this strand, student justifications were coded according to the rubric found in Table 3-9 (pg. 89, examples of student answers are included) and were developed and modified from the reasoning portion of the "Claim, Evidence, Reasoning" (CER) framework (McNeill & Krajcik, 2007, 2011). Within the CER framework, reasoning includes scientific principles being applied appropriately. The focus here was not to look at how well they were able to normatively explain phenomena, as this was coded as part of strand 2. Rather, this followed the description of strand 3 in *Learning in Informal Environments* (National Research Council, 2009) and searched for how well students were able to support their answers even if they were incorrect. For example, one student explained incorrectly that the sun would always be toward the west, reasoning that it is warmer out in the west coast (i.e. California) and therefore the sun would always have to be in that direction. Though this idea is non-normative, she justifies her answer by connecting evidence of where it is warm back to her answer opposed to hearsay or "just guessing". She simply did not have all the facts and proper observations.

As discussed above, I did not consistently ask students to justify their answers and they did not consistently do it on their own. As a result, anytime a student answered a question such as "how do you know?" or "why do you think that?" their answer was coded. Additionally, anytime students gave an explanation spontaneously, this was coded (e.g. they started saying "because…", "if this…then that…", "since…").

Table 3-9 Justification rubric

Level 0 UNJUSTIFIED	Level 1 PARTIALLY JUSTIFIED	Level 2 PARTIALLY JUSTIFIED	Level 3 PARTIALLY JUSTIFIED	Level 4 JUSTIFIED
No Justification or they just ramble ***"I don't know"*** ***"It's just what I guess"***	Justification through hearsay or statement of fact ***"my parents tell me"*** ***"It just always sets in the west"***	Justification only through evidence or observations - Stating facts without connecting it to the answer ***"I just look up and there's the sun"*** ***"Because we went to the planetarium and saw it"*** ***"If you are driving, you can see it move with you"***	Justification with clear logic of how they came to their answer, though not explicitly stating their assumptions ***" it's the middle of the day and it's probably going to be in the middle because then it's going to start moving down" (no mention of arc motion)***	Justification with clear logic of how they came to the answer, explicitly stating their assumptions ***"Because the spring and fall, the days are a little shorter than the summer, so it has a shorter arc."*** ***"Because it rises in the east and then makes an arc over to where it sets in the west."***

These codes were used as a starting point to choose 4 students to show vignettes of their justification and reasoning process to describe what their justifications looked like before and after the curriculum. Vignettes of a subsample of students were chosen in order to richly and precisely characterize trends and differences in justifications on account of the inconsistent answers. In order to show some differences and range in student answers and to avoid bias, I made a stratified intensity selection with 2 students that showed improvement in their justifications and 2 that showed no improvement or a decline in their justifications level of improvement. Level of improvement was based on the average level of justifications as determined by these level codes between pre- and post-interviews. Counting of codes can be used as a means of finding themes within datasets, so counts of level codes were used with each student to identify a theme and pattern to the types of justifications the offered in pre- and post-activities, as (Miles & Huberman, 1984). To further identify themes within levels, short reflective remarks that described additional details of justification types were used (Miles & Huberman, 1984).

Student Work

Table 3-10 Observation lists rubric

LEVEL OF COMPLETE-NESS	Level 0 INCOMPLETE	Level 1 MOSTLY INCOMPLETE	Level 2 MOSTLY COMPLETE	Level 3 COMPLETE	Level 4 BEYOND COMPLETE
Content of List	What they say is not related to the predictions made	Matches the prediction, but is incorrect or omits what needs to be observed and the times it needs to be observed OR indirect method of observation	Matches the predictions, correct for either what needs to be observed or the time it needs to be observed, not both	Matches the predictions, correct in what needs to be observed and what time it needs to be observed	Matches the Predictions, states what needs to be observed and time it needs to be observed and states further steps than was asked
Examples from Students	***"You would have to watch the moon (when it's predictions about the sun)"***	***"You would go see where it is and record it"*** ***"Go on the internet and check"***	***"You would go outside and record where the sun was at noon" (when the prediction is for when the sun is due south)*** ***"Check where the moon is" (prediction is for the phase)***	***"You would have to look at the sunrise on the first day of summer, fall, spring, and winter"***	***"You would have to go outside of the first day of each season and look at sunrise, toward the East"*** ***"…check against what you predicted."***

Another important aspect of scientific reasoning is being able generate evidence and design scientific experiments with the purpose collecting data to test hypotheses or predictions (National Research Council, 2007, 2009). Experimental design was not explicitly addressed in this curriculum, though students did have an activity that addressed this aspect of strand 3. Student groups made lists of observations they would need to test predictions they made. These lists were used to study how well students were able to create a set of observations needed to test ideas, a skill most astronomers need and use.

To analyze this, I followed a inductive approach first followed by a deductive approach, similar to grounded theory (Miles & Huberman, 1984; Patton, 2002). For this, I first read through all of the lists students made and looked for emergent themes related to completeness through reflective and marginal remarks. From this I made a rubric that represented the different levels of completeness and then coded all of the lists according to that rubric (Table 3-10, pg. 90). The rubric was iteratively tested and modified to ensure it addressed all answers students gave. The rubric includes examples from student work that illustrate each level of completeness.

Students made lists for 4 sets of predictions. These included the observations needed for checking the diurnal motion of the sun for one day, the seasonal rise positions of the sun, highest altitude of the sun through the seasons, and the shape of the moon over 4 weeks. The levels of completeness were aggregated together across all 4 types of observations for 11 groups of students. This was a total of 44 lists that students generated. The frequency of each level of completeness was then calculated as a percentage of total responses and plotted in a bar graph to highlight any trends.

3.6.4. Strand 4: Reflecting on Science

Likert-scale Surveys

The survey items for strand 4 were given as a means of gaining a first-hand account of students' ideas on the nature of science to see if they viewed science as a process. The survey had 4 items relating to science as process, and were all worded in a positive manner, meaning agreeing with the statement showed they viewed that science was a process. Again, N=25 students completed the survey items related to this strand, giving a total of 100 responses from students. The analysis was done similarly to other survey questions with the aggregate number across all 4 items. The percentage of the answers per Likert point was calculated and plotted in a bar graph to show any trends in how students answered.

3.6.5. Strand 5: Using Tools and Language of Science

Video and Audio of the Classroom during Pre-activities and Projects

Video was studied for any use of tools that students used while either making their first round of predictions or while making their project. Tool use was not emphasized in the curriculum, though the teacher did encourage students to use resources such as the Internet and books to answer questions they came up with.

Again, tracking data has been used previously to study how visitors use and engage with exhibits (National Research Council, 2009). Videos were analyzed to look for or track tools being used. Whenever a student used a tool, the kind of tool the student used and what the student did with the tool was recorded. Anything that seemed to help students in "doing science" (e.g. answer a question, design or build their projects with some level of precision, work through a problem) was considered a tool. This included but was not limited to drafting compasses, a compass rose, rulers, and reference sources for extra information (e.g. internet). Items that students used that were not specific to the design of their project were not considered (e.g. glue, scissors). In times where it was unclear what the students were doing with the tool or what students were using, audio was used to check and what was discussed and conversations related to the tool were transcribed.

Interviews with students

One purpose of the pre- and post-interviews was to study the students' language and see if they used the astronomical terms after exposure during the curriculum. Having a grasp of the language of the science is important for communicating results, a modern science practice (National Research Council, 2012), and participating productively in any science-based conversation (National Research Council, 2007, 2009).

To study this, I chose key terms and studied how students used them before or after the implementation of the curriculum. A total of five terms were chosen including 2 related to sky navigation and 3 related to lunar phases. The navigation terms were "zenith" and "degrees". These two were chosen because they have very specific astronomical meaning related to describing positions in the sky as opposed the cardinal directions, which are used commonly outside of astronomical and scientific meanings (e.g. in street or city names). The terms related to the lunar phases were gibbous moon, quarter moon, and new moon. These were chosen because they are less common phase names. Full and crescent moon are far more common in everyday language (e.g. the wolf howls at the full moon) and therefore students were more likely to have been exposed to their proper usage prior to the curriculum.

The analysis was done iteratively and inductively separately for each term using strategies suited to interviews and description of data (Miles & Huberman, 1984; Patton, 2002). Transcripts of the interviews were read looking to find any use of the term. Marginal remarks were made on whether or not the term was used correctly and how it was used. These notes were used to find emergent themes and patterns across the students on usage in the pre-interviews and the post-interviews. Additionally, counts were made for how frequently students used each term before and after the curriculum to gain a sense of how well the terms were adopted by students.

3.6.6. Strand 6: Identifying with the Scientific Enterprise

Likert-scale Surveys

The survey questions for strand 6 were given as a means of gaining a self-report of whether or not students saw themselves as astronomers and if they viewed astronomy as relevant to them. The survey had 4 items relating to identification with the scientific enterprise. Of the 4 items, 2 were worded in a positive manner as discussed before and 2 were worded in a negative manner meaning disagreeing showed they identified with the scientific enterprise. Again, 25 students completed the survey items related to this strand, giving a total of 100 answers from students. The analysis was done similarly to other survey items with the aggregate number across all 4 questions, except the negatively worded item results were reversed prior to aggregation to reflect consistent forms of answers. The percentage of those 100 total answers that were marked per Likert point and calculated and plotted in a bar graph in order to show any trends in how students answer.

Chapter 4
RESULTS

4.1. Overview

This chapter presents the results of data analysis pertaining to Research Question 1:

- **What examples of the 6 strands of informal learning are seen during the implementation of a SMILES-based curriculum that integrates learning across planetarium and classroom contexts?**

Within this chapter, I will describe the results by strand of informal learning. There will also be some brief discussion on occasion on how the results show or do not show examples of each strand being present. A summary of results is given at the end of each strand section with the exception of strand 4 and 6, as these are very brief sections. Further discussion and synthesis of the results will be addressed along with the second research question in the following chapter.

4.2. Strand 1: Sparking Interest and Excitement

4.2.1. Likert Survey Results

The Likert survey results offer a more global sense of whether or not students' interest and excitement for astronomy was sparked. Values of 1-5 were assigned to the Likert points. The value assigned to each point and percentages of responses are shown in Table 4-1 (pg. 96), along with a break down of percentage of answers by question. The far right column shows the total number of responses by survey point. The percentage of students who answered each survey point for each question is shown in the middle 4 columns. Figure 4-1 (pg. 96) shows the same percentages in bar graph form to highlight trends in student answers. The colors/patterns in each bar represent the frequency of those options for each survey question.

Table 4-1 Likert survey response percentages for interest and excitement

Survey Option	I enjoyed the planetarium visit	The planetarium visit was interesting	I would like to learn more about astronomy	I think astronomy is fun	Aggregate Percentages of Responses
5 (Strongly Agree)	76%	76%	20%	12%	46%
4 (Agree)	16%	20%	48%	60%	36%
3 (Neutral)	8%	4%	24%	24%	15%
2 (Disagree)	0%	0%	8%	4%	3%
1 (Strongly Disagree)	0%	0%	0%	0%	0%

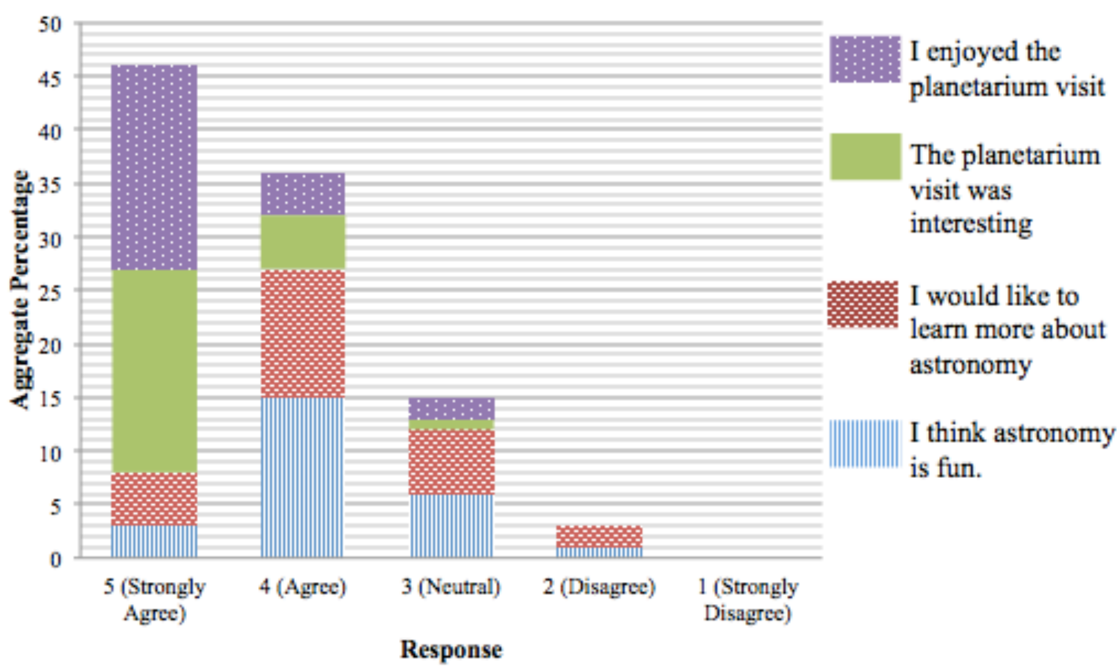


Figure 4-1 Aggregated responses to Likert survey questions on interest and excitement

The aggregate scores show a trend toward students agreeing and strongly agreeing with items regarding their interest and excitement toward astronomy and the planetarium visit. Strongly Agree was the most represented answer with 46% of the responses. A majority (86%) of the responses were either strongly agree or agree. Furthermore, no student strongly disagreed on any items related to interest and excitement and no student disagreed or strongly disagreed on items relating specifically to the planetarium. In fact, 76% of students strongly agreed on items related to planetaria.

4.2.2. Mini-Case Studies of Student Groups Working on Projects

Four student group mini-case studies are discussed below and address what students' engagement looked like as a means of assessing the presence of interest and excitement. The case study reports begin by giving a narrative and thick description on how the students engaged. Since students were in groups of 2, I will also highlight important differences and similarities between the students and interesting episodes over the two days. At the end of each case study there will also be a short discussion and summary on the group's engagement and if it shows evidence for interest or excitement toward astronomy. The codes found for each group discussed in the previous chapter will also be summarized by frequency in a table.

Mini-Case Study 1 – Gina and Olivia

On-Task vs. Off-Task Time – Gina and Olivia appeared rather engaged with their project, spending over 90% of their time on-task as determined by listening to audio and video described in the previous chapter. A lot of this time was spent discussing, planning, and asking questions about what they could do for a project. Olivia showed a greater amount of time on-task while Gina's attention was more likely to wander to other students' projects or to casually ask questions about astronomy such as “I wonder when the next solar eclipse is” or “Why is the Milky Way called Milky?” These moments were often short-lived as Olivia would display project manager behavior and ask Gina to focus. Gina would always oblige immediately.

Deciding What to Build – Gina and Olivia spent most of the first day and a half discussing what they wanted to build for their project and how they could compromise on their different ideas. They would seemingly come to an agreement and start working on that idea, but new arguments would erupt. They acknowledged the tension and on a few occasions asked for help from an educator to resolve their disputes. They both explicitly mentioned their disagreements as their least favorite part of the project on their surveys.

Here is a discussion they had when brainstorming ideas that illustrates their disagreements. Gina wanted to do something related to the phases of the moon and Olivia wanted to do something related to the sun:

L1. **O(livia):** I think we should do the position of the sun for hours. Do you think that’ll work?
L2. **G(ina):** I don’t think I can do that because…or looking at the sun. *[in a contrived flustered voice]*
L3. It’s 3 o’clock, sorry guys I’ve got to get out of class and take a look at the sun.
L4. Uhhhhh.*[inaudible]*. What about months, phases of the moon?
L5. **O:** What about length of shadows?
L6. **G:** I don’t know how…I want to do phases of the moon.
L7. **O:** I don’t think you have to do it every single hour. You can do it at like lunchtime, in the
L8. morning, a little bit before bed at like 6 o’clock, like when you leave school. I think you’re
L9. allowed to do it that amount of time too.
L10. **G:** Really, I think phases of the moon would be better.
L11. **O:** I think that one would be harder to do
L12. **G:** Why?
L13. **O:** Well...*[interruption by intercom]*. It’s for months, so it might take a while.
L14. **G:** You would have to look for the moon every day.
L15. **O:** [*inaudible*] What if you can’t do it?
L16. **G:** [*inaudible*] Maybe sunrise and sunset
L17. **O:** That wouldn’t work out as well. I would rather do the phases of the moon than sunrise
L18. and sunset.

They found it very difficult to agree on what they wanted to do, with each one persistently advocating for her own idea. Gina in particular showed devotion to her idea, saying at one point it is just what she wants to do (L6). However, she also attempted to find a different idea they could both agree on when she brings up sunrise and sunset (L16). Olivia rejected that idea immediately (L17). She also focused specifically on the ease of ideas that are being proposed as a criterion for selection of their project (L11), something she referred to on multiple occasions throughout this process.

Discussions of this nature were frequent while they worked on their project over not only the kind of time they wanted to measure, but also materials to use and how exactly to construct their project. Though the two students did argue, they continually listened to each other and found a compromise through discussion and advice from educators. The project they settled on involved a sun that could rotate on half of a paper plate to match the position on the sky. The position on the paper plate told the time of day. The other half of the paper plate was similarly constructed, but used a full moon to tell the time of night. This was shown as an example in chapter 3 (Figure 3-3, pg. 67)

Thoughtful Discussion and Planning – A large portion of their time involved discussion on how they would build their project. They planned everything out carefully to make sure their design was functional and easily understood by anyone who used it. For instance they discussed what sort of clarifying information they could add to their project (e.g. they wrote that times were approximate since sunrise and set times change), if they should use markers or colored pencils, the best materials for construction, and the size of rotating sun and moon. Even when they finished their plan, they found ways of improving their project such as adding additional times for added precision while still being careful to keep it readable.

The girls also displayed deeper level discussion related to why their project worked by asking thoughtful questions and reasoning through design aspects of their projects. Here is one discussion from when they labeled directions on their device:

L1. **O(livia):** Okay that's our horizon. Like that, Gina? Horizon?
L2. **G(ina):** Yeah
L3. **O:** And then we've got
L4. **G:** A stick
L5. **O:** 1 o'clock. And then…which way is south again? That way? So this is south, so that
L6. would mean…is that sunset over here?
L7. **G:** Num…let me see.
L8. **O:** There's our 1 o'clock
L9. **G:** If this was…well, then this would be its east and that would be its west.
L10. **O:** Uh, I don't think so.
L11. **G:** This is North, this is east, this is south *[sounding frustrated]*
L12. **O:** That is north
L13. **G:** That way is east, south. South! For the moon. East is over there for the moon.
L14. **O:** Okay, so east…west…this is south up here
L15. **G:** Yeah.
L16. *[Some inaudible conversation]*
L17. **G:** Well, for this would be north.
L18. **O:** So this is still south over here. I think we would still look south if we were looking for
L19. the moon. Is this still south?
L20. **G:** Yeah
L21. **O:** Which way is over here, if we are facing south
L22. **G:** Then that would be east
L23. **O:** Are we sure, we are still facing the same way.
L24. **G:** If this is the sun, then…If this is the moon, then that would be east.
L25. **O:** If this is sun...
L26. **G:** Uhhh…
L27. **O:** Is that good?
L28. **G:** Yeah.

They tried to work out which direction is which. They already established previously they would see the sun toward the south during the day, but with the moon used on the opposite side of the paper plate, this lead to some confusion. Namely they needed to realize that where you label east and west on either side of the paper plate would be reversed once you flipped the device over. This discussion shows them working through this, asking questions, and using what they know about the directions, the sun and moon to reach that conclusion. Olivia in particular wanted to make sure she understood what was going on.

Summary and Discussion of Gina and Olivia – Gina and Olivia's engagement indicates at least some interest as they discussed the content and use of their project frequently, asked questions about astronomy and how the project related to what they knew and showed thought as they planned out many aspects of their project. Gina did show instances of being off-task, but they were very short-lived any many of those instances still showed a curiosity in astronomy that might indicate interest.

The girls did have many disagreements about the project, particularly what to work on and content as seen in their working through how to label directions. However, this showed perseverance of a sort. They were adamant about discussing new ideas and sticking with their own ideas. This shows an attachment to what they wanted to do. They also persevered through their disagreements to come up with suitable solutions that they thoroughly discussed and planned out. These behaviors in general are often tied to mastery goal learning orientations that can be tied back to intrinsic motivation and interest (Schunk et al., 1996).

Table 4-2 Summary of engagement codes for Gina and Olivia

Code	Description	Code Frequency	% of Subgroup
	Level of Engagement		
SURF	Surface level engagement	26	44.8%
DEEP	Deeper level engagement	32	55.2%
	Activity		
PLAN	Planning how out their project	19	19.4%
BUILD	Physically building their project	8	8.1%
DISC	Discussing the project	37	37.8%
ASK	Asking questions	15	15.3%
PM	Exhibiting "project manager" behavior by telling students what to do	0	0.0%
ON	Miscellaneous on-task behavior	1	1.0%
OFF	Off-task behavior	14	14.3%
OOT	Off-topic discussion while doing an on task activity	4	4.1%
	Characteristic of Activity		
EASE	Focusing on the ease of the project	11	26.8%
CURI	Expressing curiosity or interest	4	9.8%
PERS	Persisting or persevering through obstacle	11	26.8%
LPERS	Lack of persistence or perseverance	4	9.8%
PRIDE	Expressing pride	1	2.4%
GOOD	Desire to do well	9	22.0%
FAC	Being factitious/ flippant	1	2.4%
	Who was involved		
TEA	Another teacher or educator	9	75%
OTH	Other Students	3	25%

Many of their reactions and reasons for doing certain projects could also be tied to a possible lack of intrinsic interest, however. This is seen with Olivia's focus on doing projects that seemed easier to her. Focus on ease is seen with students that have performance goal orientation and could suggest that she is not really interested in astronomy but only in gaining a good grade or simply wanting to get her work done. It has been noted that this does not exclude interest, as interest and a performance goal orientation can be concurrent depending on the context (Schunk et al., 1996). Olivia did state that she really enjoyed working on her project in her survey.

The exact level of interest is difficult to tell, particularly with Olivia. Other motivations could be present, suggesting lower levels of interest. Despite this, interest appeared to be present with these girls as evidenced by an overall deep level and nearly constant engagement with the task.

Mini-Case Study 2 – Lucas and Walter

Deciding on a Project – Lucas and Walter worked on a sundial for their project like many other students in the class. This decision was made during a 10-minute brainstorming session students had just before a weeklong break. Walter was absent that day and Lucas made the decision without him after listening to other students discussing sundials. Their sundial featured interchangeable templates that originally depended on the direction the sundial faced. However, in their final version the templates depended on which city you were in.

Overview of Group – The boys spent a majority of their time on-task (~90%) as determined by listening to audio and video described in the previous chapter. Walter was a quiet student who focused on the work at hand, only becoming distracted for short periods of time by Lucas or neighboring students. On some occasions he acted as a project-manager trying to get Lucas's attention to bring him back on-task. Lucas was off-task more frequently, being distracted by nearby students, playing tricks on his friends, or discussing other school subjects. Despite this, he also showed many self-regulatory behaviors such as writing information down and bookmarking his notebook with sticky-notes as reminders of work he had to do at home. He also chastised neighboring students on several occasions for not working, exhibiting some similar project-manager tendencies as Walter.

Working on the Project – Lucas and Walter frequently worked on surface level and mundane aspects of building and discussing their project, such as if they should use roman numerals to label the times and cutting out templates and labeling them. This could be attributed to them doing a lot of work outside of class. On the first day they worked on their projects after their week-long break, Lucas came in with a cardboard sundial already made. Since they had not worked on it at all in class it can assumed he built this over the weeklong break at home. He also explained that he and his dad discussed ways they could check to see how it worked. The next day in class, Lucas brought in a list of times and corresponding angles on a sundial that he had found and researched online the night before. As a result, everyday in class they already had the information they needed to build their project and all they needed to do was the surface level aspects of the project.

They did frequently display deeper level thought about their project as well, particularly in discussion with educators. For instance, their teacher grilled them about how they might figure out where the labels would go and how their sundial might work. Here is an excerpt from a conversation with their teacher highlighting some of their thoughts:

L1. **T(eacher):** Well, now I have another question for you. Let's say you have it facing North
L2. right now. Is your sundial supposed to face North? East? South? West? Or does it not

L3. matter?
L4. **L(ucas):** Uhh
L5. **W(alter):** Umm
L6. **L:** It sort of does matter, if you put it North and all the time you are gonna put it down to
L7. see what time it is, you going to have to put always North.
L8. **T:** Okay, so. I would agree with that. It probably doesn't matter so much which way it
L9. faces, is that is always faces that way.
L10. **W**: It's always faces the sun.
L11. **T:** So, explain to me how the shadow works. So, if this is facing North, where, like in the
L12. beginning of the day.
L13. **L:** The shadow would probably be around here.
L14. **T:** Okay, why?
L15. **L:** Because the sun's coming up and it'll come out there, so it will probably hit here and
L16. go down.
L17. **T:** So, what kind of shadow is this gonna make by the way?
L18. **L:** It's gonna.
L19. **W:** It's gonna be like, It's gonna be like err, kinda like that.
L20. **L:** It's gonna make a really large shadow isn't it?
L21. **W:** It's gonna get…
L22. **T:** So you are gonna go by where the edge of the shadow or something?
L23. **W:** Well, this outer edge.
L24. **T:** Oh, so where the tip of the shadow is then. Are you thinking the tip of the shadow or
L25. the edge of the shadow.
L26. **W:** Well this tip would usually where all the clock movements are.

Their teacher is seen walking them through how the sundial works, but they clearly are thinking about how to best use the shadow and where the shadow might fall. Walter even made an explicit connection between sundials and clocks (L26). Immediately after this portion of the conversation, they discussed how they might test out their sundial with their teacher. After first discussing how they could take it outside and check it every hour they also discussed using a flashlight to simulate the sun's movement, showing some deeper thought and engagement with experimental design for the project. After their teacher left they continued this discussion. They paid attention to details, writing everything down and going so far as to make sure they had a way of recording the information they gathered. In a later conversation with their teacher, they also stated they wanted to compare their results with other people's work, something scientists might do.

Managing the Project – Both Walter and Lucas participated in cutting out templates and labeling times on the sundial. However, Walter did the brunt of it this work. When he was not sure what to do, he would ask Lucas what he thought and they would have discussions on what made more sense. Here is an excerpt from when they were labeling the times on their sundial:

L1. **W(alter):** Okay. Where do we put the think in. We have to make sure this thing isn't blocking one
L2. either
L3. **L(ucas):** There, so we could probably write up down here.
L4. **W:** Well, what I was thinking we could do…That's 12. Now let's like, umm
L5. **L:** Next, that's like 12:45 would be right next to it and 12:15 would be over here. You just draw a
L6. line for that and it would be 2 degrees. 2 and half.
L7. **W:** 2 and half, so. Mmkay.
L8. **L:** This is gonna be hard to do.
L9. **W:** C'mere, we are are gonna have to take this out and in order to do the angles and everything.
L10. **L:** I got a bigger one. I got a bigger one. [*handing Walter a bigger protractor]*

Lucas seemed to spend more of his time acting as a form of project manager, even making sure that Walter had an appropriate sized protractor (L10). Though Lucas showed some lack of interest in accuracy at one point when he cited how their teacher "said it doesn't have to be completely right", he did do quality control checks. He asked Walter what things were and pointed missing labels out to him. Walter also frequently made similar checks on his own; making sure the gnomon was sitting properly on the sundial. When they did test the sundial with a flashlight, Lucas showed pride by announcing excitedly to several people on at least five unprompted occasions that their sundial worked.

Initiative and Curiosity – Both Lucas and Walter showed initiative and curiosity while working on their project beyond work outside of class time. At one point I talked to the students and pointed out to them that the online calculator they used allowed them to change the latitude they were at and not the direction of the sundial pointed. I encouraged them to consider that there might be a particular direction where sundial was more useful and that changing cities in their templates may be more useful. They later looked up other latitudes on the computer and mused about how a shadow at the equator would always be at 0 degrees. This seemed to pique their curiosity and several minutes later they are heard wondering about other locations in the world:

L1. **Lucas:** What if we did Rio, Brazil, that would probably be crazy.
L2. **Walter:** Brazil is like right in the middle, it's not like east and west, it's like in the middle of
L3. the compass.

They also showed curiosity in other, more individual ways. For instance, Walter seemed to have looked up information previously as there were multiple occasions where he randomly dropped facts about sundials into the conversation such as the "fin" that casts a shadow is called a gnomon.

Lucas's curiosity was displayed differently. As discussed above, he worked primarily as a project manager, checking what Walter was doing. In between his checks, he would frequently walk away from Walter and visit other students, asking questions about what they were doing. In some cases he shows simple curiosity about other projects:

L1. **Lu(cas):** I wanna see what Laura… *[to other students]* Laura, what are you *[inaudible,*
L2. *walks away to their desk]*?
L3. *[At Laura and Wendy's desk]*
L4. **Lu**: Are those like all the planets
L5. **La(ura):** Yeah, and then the sun and the moon are there.
L6. **Lu:** That's cool. *[inaudible]*?
L7. **La:** The sun and the moon, they kind of move.
L8. **Lu:** Where's Earth?

In other cases, he started telling others how to do their project as when he talked to Garrett and Evan, who were also making a sundial:

L1. **L(ucas):** What direction are you putting your sundial in?
L2. **E(van):** We are just going North
L3. **L:** If I were you, I would not tape yet.
L4. **G(arrett):** Without the tape it would just be like
L5. **L:** No, dude, don't tape it all the way. You're gonna have to put the thing that makes the
L6. shadows
L7. **G:** I know, I'm not stupid, I own one.

Lucas seemed to want to help these students, but Garrett at one point reacts negatively (L7). It could be that Lucas just wants to show off his knowledge of sundials. However, the fact he shows such curiosity without interjecting his opinions on how other people should build their projects at suggests he was simply interested in discussing ideas.

Summary and Discussion of Lucas and Walter – Overall, Walter and Lucas are engaged with their project. They were limited in their off-task behavior, though it was higher than Olivia and Gina. Some off-task behavior is expected in effective classrooms though (Lee et al., 1999), and a high percentage of their time was engaged in building the project.

They also show initiative in getting their project done as seen by their outside work. This suggests they are very interested in the topic and is confirmed by their explicit statements in their survey, where they both mentioned researching their sundial as their favorite part of the unit on their survey. Walter, even explicitly stated interest when he wrote that it was "interesting to learn how the sundial worked in different parts of the world".

Lucas also showed a lot of curiosity in other people's projects and seeing how they worked, suggesting there is an interest in the topic beyond his own project. Walter showed he had some interest in the topic as suggested by his random outbursts about facts he had learned previously. These could be attempts to show off their knowledge and suggest a more performance types of goals (Schunk et al., 1996). However, there needs to be some level of interest for this amount of extra work to learn about the materials.

Mini-Case Study 3 – Lily and Nina

The Project – Lily and Nina worked on a project that involved the use of a "glow dome", a children's toy that consists of a clear plastic dome on spinning base. They used the dome as a planetarium of sorts, where you could look down on the ground "from the sun's perspective" as Nina described it. They originally planned on attaching several "suns" in different locations on

Table 4-3 Summary of engagement codes for Walter and Lucas

Code	Description	Coded Frequency	% of Subgroup
	Level of Engagement		
SURF	Surface level engagement	19	35.8%
DEEP	Deeper level engagement	34	64.2%
	Activity		
PLAN	Planning how out their project	10	8.6%
BUILD	Physically building their project	16	13.7%
DISC	Discussing the project	32	27.6%
ASK	Asking questions	14	12.1%
PM	Exhibiting "project manager" behavior by telling students what to do	15	12.9%
ON	Miscellaneous on-task behavior	7	6.0%
OFF	Off-task behavior	22	19.0%
OOT	Off-topic discussion while doing an on task activity	0	0.0%
	Characteristic of Activity		
EASE	Focusing on the ease of the project	1	4.5%
CURI	Expressing curiosity or interest	12	54.5%
PERS	Persisting or persevering through obstacle	0	0.0%
LPERS	Lack of persistence or perseverance	0	0.0%
PRIDE	Expressing pride	6	27.2%
GOOD	Desire to do well	3	13.6%
FAC	Being factitious/ flippant	0	0.0%
	Who was involved		
TEA	Another teacher or educator	10	28.6%
OTH	Other Students	25	71.4%

their dome to indicate the position of the sun at different times, though they were not clear on what type of time they would be describing (e.g. time of day or time of year based on sun rise and sun set positions). Eventually, they labeled the directions, a meridian line, and attempted to use the sun's altitude as a way of measuring time of year.

Characteristics of Their Engagement – Compared to the two previous groups, Lily and Nina were not very engaged with their project. They showed frequent occasions of off-task behavior, usually instigated by Nina. They talked to each other about television programs, gossiped, or clowned around. Lily at one point was scolded by the teacher toward the end of the second day for not sitting with Nina. They were reluctant to work at times, at one point citing an educator coming over as a reason to discuss their project:

Nina: Somebody's coming, we have to talk.

They spent a large portion of the first day off-task and disengaged. This could be partially explained by having a lack of supplies to work with as the glow dome they wanted to use was at Nina's house. They next day they spent far more of their time on-task. However, it was doing mundane surface level tasks such as cutting out and painting cardboard 'suns' while having off-topic discussions. This is not too unexpected as building is an aspect of the project and does not take a lot of mindfulness to complete. However, even when they did discuss their project over the course of the two days, there was still a lack of serious engagement.

Not Taking The Project Seriously – Nina in particular frequently acted rather facetiously toward the project. The girls wanted to add green inside their dome to represent the grass on the ground. Nina suggested she take scissors to her sister's soccer match and cut some grass to bring in. She giggled constantly as she said this, suggesting she thought it was an absurd suggestion. At the end of the first day, Nina stood up and drew attention to herself by holding a piece of ripped cardboard up and announcing to class "This is our project! This is our project!" Lily seemed embarrassed by this and asked her why she did that. The next day, the teacher asked them about the sun's they were painting to attach to their project:

L1. **T(eacher):** Why does the sun have to be on cardboard? Why can't it be on yellow paper?
L2. **N(ina):** Because it was our idea…
L3. **T**: Is there a reason it has to be painted? It can't be yellow to begin with?
L4. **N:** Because…umm [*grinning sheepishly, giggling uncontrollably*]
L5. **T:** Because you really want to use the paint.
L6. **L(ily):** Yeah
L7. **N:** Yeah [*both giggling loudly while saying this.*]

They could barely admit to their teacher that they just wanted to paint. Their giggling and grins suggest they knew it would have been a more practical idea to just use yellow paper. These episodes suggest a flippant attitude toward the project.

Hints of Deeper Thought – These girls did have fleeting moments where they showed deeper thought about their project. On the first full day of working, Nina and Lily discussed a possible project:

L1. **N(ina):** What my idea was, we could do something like you know in the planetarium, we
L2. can do a moon planetarium like a clear sky and then cardboard and the moon.
L3. **L(ily):** And the moon we could show stars at different times.
L4. **N:** We could put a line over it. We'll, they have the text areas in the sky
L5. **L:** Special days, first day of spring, first day of fall, first day of winter
L6. **N:** Does that sound good?
L7. **L:** Mm hmm.
L8. **N:** How are we gonna tell the time?
L9. **L:** Seasons.
L10. **N:** Yeah seasons. Seasons slash months.
L11. *[Several minutes of off-task behavior and discussion of decorative aspects]*
L12. **N:** And, then, Lily, we could when it has the dome and the mat we could tape a piece of
L13. paper with the sun on it and then we can say 6 o'clock and then we can move it to where
L14. the sun would be at 6 o'clock
L15. **L:** We could put the paper on the inside and then turn it for different times.
L16. **N:** Yeah! Cool.

Nina and Lily show some initial thought, thinking about using "special days" and deciding they would use this method to tell the time of year, or seasons (L5-L10). However, it's not really clear which lines they are talking about and what about the "special days" is going to be used to tell time. Later they talk more about telling the time of day, using the dome to mark the sun's path possibly (L12). But it is still not clear and this is the extent of their conversation regarding the project before deciding on how to build it.

Deeper discussions were usually with educators who prompted them to think more about their ideas. On the first day, Lily and Nina discussed the project with their teacher, showing a slightly more coherent idea:

L1. **N(ina):** What we're thinking we're gonna do is that I have this glow dome and we're
L2. gonna use half of it and use green paper and you look down from the sun's point of view
L3. and a piece of paper with different suns and do seasons and months. And we're put a
L4. thing across the sky that will say how you can tell time with it.
L5. **T(eacher):** Explain to me what kind of time you are going to try and show. Are you
L6. going to show the rising positions? So how are you gonna know where the sun rises?
L7. **N:** Um, we know it rises from one side and goes all the way across the sky and sets on
L8. the other.
L9. **T:** So it starts in what direction?

L10. **N:** It rises in the east and go across the sky to the west.
L11. **T:** Okay, east to west.
L12. **N:** You turn it to where it is, we will turn it to here and find.
L13. **T**: if it rises in the east and sets in the west. Does it always rise and set in the same place?
L14. **L(ily):** No. Sometimes moves somewhere
L15. T: Do you now where it rises different times of the year or is that something you need
L16. to…
L17. **N:** Research
L18. **T:** Research. What you can do is write a list of the things we need to find out, things we
L19. need to build, Things we need to bringing, things we need to do.

In this example, Nina explains that they will have different positions on the dome that will tell the different time of the year (L1-L3), even applying some of her knowledge about the sun's motion (L7). Their teacher leads them to the idea that they need some more information to remember how the sun's path is different between the different points of the year, suggesting they write a list of everything they need to bring, do, and research (L18). Lily and Nina initially took this advice and wrote out a list of materials they needed to bring in, including paint, glitter, and markers. However, they never mentioned the research again except once when Lily seemed to mention it to herself. The next day the teacher had them explain their project again, but expressed doubt they would be able to this:

L1. **T(eacher):** Explain what it's going to do. Let's understand this first. What are you
L2. going to do?
L3. **N(ina):** They are gonna tell.
L4. **T:** Because I don't think you can explain to me what they are gonna do.
L5. **N:** Okay. We are gonna put a letter on each sun.
L6. **T:** Yeah
L7. **N:** And we're gonna have a little paper guide thing
L8. **T:** Okay.
L9. **N:** And we are gonna say like A is supposed to be at 2 o'clock or something.
L10. **T:** Ohhh. Okay I have a question for you. Let's go look at *other students.*

Here, their idea seems to have switched to the time of day, and their teacher seems to recognize this confusion. She took them to another students' project elsewhere in the classroom. After they returned, they made no mention of it. Overall, the girls seemed to show some thought when prompted, but had inconsistent ideas, and seemed unsure how to approach the project even when given direct advice.

A Dominant Group Member – Nina also was also the dominant personality in the group, making a lot of the decisions and being the primary respondent when talking to their teacher. Here is one of the very few times Lily attempted to put much thought into the project herself:

> **Lily:** So we are gonna do a border like this and the dome will be inside there. And this is a planisphere so you know the outside of a planisphere, the some will be inside but the border won't be touching it, so we can just spin it. *Nina is writing*
>
> **Nina:** *giggling* You know too much. I can just pick grass from my house. Green grass or [*inaudible*].

Nina dismissed Lily's idea as her knowing "too much" before immediately switching the topic back to surface level decorative aspects of the project. Shortly after this Lily is seen frowning, looking off into space and exhibiting off-task behaviors such as talking to other students. Lily mentioned in her survey that one of her least favorite parts of the unit was the project, citing the difficulty of working with Nina.

Table 4-4 Summary of engagement codes Lily and Nina

Code	Description	Code Frequency	% of Subgroup
	Level of Engagement		
SURF	Surface level engagement	34	75.6%
DEEP	Deeper level engagement	11	24.4%
	Activity		
PLAN	Planning how out their project	14	13.6%
BUILD	Physically building their project	14	13.6%
DISC	Discussing the project	24	23.3%
ASK	Asking questions	18	17.5%
PM	Exhibiting "project manager" behavior by telling students what to do	2	1.9%
ON	Miscellaneous on-task behavior	1	1.0%
OFF	Off-task behavior	21	20.4%
OOT	Off-topic discussion while doing an on task activity	9	8.7%
	Characteristic of Activity		
EASE	Focusing on the ease of the project	0	0.0%
CURI	Expressing curiosity or interest	0	0.0%
PERS	Persisting or persevering through obstacle	0	0.0%
LPERS	Lack of persistence or perseverance	0	0.0%
PRIDE	Expressing pride	1	9.1%
GOOD	Desire to do well	0	0.0%
FAC	Being factitious/ flippant	10	90.9%
	Who was involved		
TEA	Another teacher or educator	11	64.7%
OTH	Other Students	6	35.3%

Summary and Discussion of Lily and Nina – Lily and Nina had some initial engagement with the content of the project; however, it was short-lived and primarily seen when an educator was present to prompt them. They rarely took these conversations to heart, ignoring advice and suggestions they were given. A significant amount of their time was off-task or showing carelessness regarding their learning. Lack of focused engagement and perseverance suggests that Lily and Nina had little, if any, interest in learning (Hidi, 2000).

Interest can be tied to intrinsic motivation, which can be affected by the level of difficulty in a task (Schunk et al., 1996). Lily and Nina were very inconsistent with their ideas and seemed to struggle with the content in their project. They both stated the project was their least favorite part of the unit in their surveys. Lily stated she did not know what she was doing and Nina said she "did not understand this unit very well." Thus, this project or unit as a whole may have been too challenging for them, resulting in them becoming less engaged and motivated to do the project, and thus less interested.

Social aspects seemed to also play a role as well as Lily's off-task behavior seemed to result from Nina. Lily agreed on her survey that she would like to learn more about astronomy, while Nina disagreed. This suggests that Lily might have had a stronger interest than Nina in astronomy. However, Nina's dominant personality may have caused Lily to lose interest during the project and become disengaged.

Mini-Case Study 4 – Astrid and Georgia

Deciding on a Project – Astrid and Georgia worked on a traditional style sundial that had a triangular gnomon to tell the time. Georgia made this decision during a 10-minute brainstorming session a week before they started working on their project while Astrid was absent. It appeared that Georgia heard other students talking about sundials, found it to be an interesting concept and wanted to know more:

> **G(eorgia):** Alexis, have you seen a sundial before? What is it like?
> [*Neighboring student explains a sundial to Georgia]*
> **G:** Oh, cool.

Astrid did not seem bothered by this idea when she came back to class after break and listened to Georgia when she explained it to her. They did not discuss many other ideas for their project, but did ask a lot of questions about how sundials worked.

Asking Questions – In the first full day of working on their projects, Georgia and Astrid asked questions relating to sundials, making sure they understood how they worked. They did this through discussion with Alexis, whose partner was absent that day, and their teacher. Georgia primarily asked very deep level questions that showed she really wanted to understand how sundials worked. Here is an excerpt of their early discussion with:

> **Ge(orgia):** We need something that casts a shadow then. Should we put a straw in the middle?
> **Al(exis):** Like this
> **Ge:** Wait, so this is like to cast a shadow?
> **Al:** Something like that
> **Ge:** What's this though? Like a triangle kind of thing?
> **Al:** Yeah like a triangle
> **Ge:** What does that do?
> **Al**: It casts the shadow
> **Ge:** Okay.
> **As(trid):** Georgia, do you understand it?
> **Ge**: Do you understand it?
> *[Astrid shakes her head no.]*
> **Ge:** It's like a clock. mmmm [*drawing]*. And this is like a triangle thing and this is the edge and go up down like that. This casts a shadow on what time it is.
> **Al:** It depends on the angle of the sun
> **As:** Do you have to hold it up to the sun?
> **Al:** No.
> **Ge:** It sits in your yard. Basically how it works is when the sun hits this, it casts a shadow of it. The shadow is directly behind. So where the sun hits, it's right behind. So if the shadow hits here, if the shadow will be right behind.
> **Al:** If the sun hits it here, the shadow will go behind and hit over here, like Georgia said. If it hits it this way, then it will be that way.
> **Ge:** So Basically it's by telling by looking at the sun. If the sun is at a position it means it's a certain time and this is how you can tell. Doesn't it have to face a certain direction? You sure?

Georgia asks questions about how it could be built, focusing on the functionality first, such as whens she notes they need to use something that will cast a proper shadow (L1). Later she also asks a question about which direction it needs to face (L25-L26) suggesting she is also thinking about how the sun moves and how that movement might affect how the sundial works. Later, she is not satisfied with the answer she has and asks Alexis again, showing persistence to understand as well. Georgia also makes sure her partner understands how the sundial works and shows understanding of the functionality when she explains it to Astrid (L14-L21). Astrid also asks a question regarding functionality (L17) showing she is thinking about how it might function.

Though Astrid asked a few questions in this first day, she did not ask them as frequently as Georgia. Overall she kept her end the conversations to design aspects of the project. Her engagement remained primarily at the planning stages with Georgia, where they started making lists of what they needed to bring and research without prompting. Here is an excerpt of Astrid's contribution throughout the first day.

L1. **A(strid):** Should we use cardboard or paper?
L2. **G(eorgia):** Cardboard
L3. **A:** Have cardboard and then paper on it?
L4. **G:** Yeah. So it's like white and you can see the shadow. Alexis said black would be
L5. easier.
L6. ……
L7. **A:** I have this really thick black marker to bring in
L8. **G**: We need to find out if it needs to be facing a certain direction
L9. [*start writing down what they need to find]*

They worked on their lists of what they needed to find out and supplies to bring in the next day rather diligently. At one point neighboring students tried to distract them and they worked through this, paying no attention to the boys. They made sure to not only understand how the sundial worked first, but also make sure they had reminders on how to build it.

Understanding Sundials – The girls also showed openness to suggestions and working through their idea, after their teacher prompted them to think through some of their questions rather than looking the answers up online. Here is an excerpt from a very long conversation where their teacher walked them through why a sundial worked:

T(eacher): I'm gonna interrupt you because Alexis was just asking. How a sundial
works. Instead of looking up and typing in google How a sundial works and reading their
answer, what could you do to figure out how a sundial works?
G(eorgia): Well the sun is in the east early in the morning, more 1ish in the morning,
more like 7
or 6.
T: Yeah, people will say sunrise 6 or 7 in the morning even though it can be earlier or
later.
G: So maybe this should be facing east and then the sun, when it gets higher it will hit
this at different point and it will cast the shadow
T: It will kind of move the shadow. So when the sun is in the east and let's say you have
a stick here or a triangle. Where would your shadow probably go if the sun's in the east.
G: It's down here probably.

Georgia was the primary respondent when the teacher interacted with them, while Alexis and Astrid both intently listened. Georgia shows some thought about how the sundial works here and is willing to walk through her ideas when prompted.

At one point during their discussion, Astrid and Georgia commented on how easy their project was:

Astrid: This is going to be easy
Georgia: This is gonna be really easy. We can write a paper on..wait we can't write a
paper on how it works if we don't know how it works.

Georgia and Astrid seemed to be glad in how easy their project is to them, suggesting this in an important aspect to them. However, unlike Olivia and Gina discussed above, their focus was not on ease as a criterion for choosing their project. Their comment suggested that they found this topic understandable after asking many questions and showing effort to understand it. Astrid in her survey also confirms this when she stated, "it was something I never thought I could do, at first it seemed hard but now that I've done it, it is easy now to think of making a sundial."

Understanding other Projects – The girls also showed some initial engagement in understanding a neighbor's project that looked different. However, this was not sustained and quickly turned to judgmental tones. This is seen when Georgia asked them questions like "How would that even work?" and "How could you tell the sun is even there?" After listening to their neighbors explain their project, she said "whatever", looked away and ignored the boys. Their engagement beyond their own sundial was limited and it seemed they put little effort into really listening to ideas outside of their project.

Unsustainable Engagement – Despite this initial engagement with the content and how sundials worked, it was not a sustained engagement on the first day and only lasted for the first half of class. After they had figured out how sundials worked and had a plan for the next day, they stopped working. Georgia put her head down and at times appeared to be napping. Astrid just sat at her desk looking around. The only time they came out of this reverie was when an educator stopped and talked to Alexis. They listlessly repeated their plan until the educator left. It seemed as if they simply wanted the illusion of working because an authority figure was nearby. Toward the end of class when the teacher gave a concrete suggestion to write out a step-by-step building plan, they did so immediately. However, they quickly completed the task, noting when they were finished. When asked why they had stopped, they explained it was because they were tired at the end of the day and needed supplies. Though this is reasonable that they did not have all the necessary supplies, they did not seek out other ways to engage.

The next day the girls were more consistently engaged with the project. Their focus was more on building their sundial out of cardboard. They had a few brief moments of thinking more deeply about how their project worked:

L1. **G(eorgia):** Now, we have to find how we can find
L2. **A(strid):** How we can cover that up

G: Yeah, we can put this on. Like we need to figure out where we need to put it on.
[*talking about the gnomon]*
A: What should we make it out of? We could make it out of this. Cut a triangle out of it.
……
G: We can't start writing on it, because we need.
A: So we should make a mark right there
G: but we can't do it without the but flashlight because we need to use the flashlight like the sun.
……
A: Maybe we should cover that up
G: Yeah…now we just need to cover this side up. Can you trace over it?...Now we just gotta like draw the numbers on and then yeah
A: I feel these should be six and these should be 12
G: Yeah, the sun is never gonna go over here, this is like the arm

Astrid and Georgia both asked questions about how they should build the project, wanting to make sure that they are able to test certain things before finalizing and thought about how the sun will move when putting everything together. They did not blindly follow directions, but displayed care and understanding that everything worked properly. Eventually they also discovered that their teacher had a working flashlight in which to test out sundials and make more accurate time markings. They made sure to get theirs tested out before finishing up the final product. Once this was done, they made finalizations and planned out their work for the next day.

When they felt their sundial was finished about 10-15 minutes before the end of class, they decided they would continue working the next day on writing their presentation and started cleaning up. They did start planning out the next day again. However, their engagement did not continue to the end of class again. This could be explained by it being the end of the class and their immediate action to tidy up their workspaces, but it also showed they were not as absorbed as other students.

Summary and Discussion of Georgia and Astrid – Georgia and Astrid showed strong engagement with the topic and thorough thought and planning of their project. Even when building, when other students showed more off-topic discussions and simply put things together, they showed thought about how the design is affected by how the sun moves and making sure it was functional. Deeper level thought and asking questions are signs of interest (Hidi, 2000), suggesting the girls had at least some interest in sundials. This is also confirmed in their survey answers where they both stated that their favorite part of the unit was making the sundial and figuring out how it could be used to tell time.

Table 4-5 Summary of engagement codes for Georgia and Astrid

Code	Description	Code Frequency	% of Subgroup
	Level of Engagement		
SURF	Surface level engagement	19	41.3%
DEEP	Deeper level engagement	27	58.7%
	Activity		
PLAN	Planning how out their project	17	21.0%
BUILD	Physically building their project	13	16.0%
DISC	Discussing the project	14	17.3%
ASK	Asking questions	18	22.2%
PM	Exhibiting "project manager" behavior by telling students what to do	1	1.2%
ON	Miscellaneous on-task behavior	2	2.5%
OFF	Off-task behavior	15	18.5%
OOT	Off-topic discussion while doing an on task activity	1	1.2%
	Characteristic of Activity		
EASE	Focusing on the ease of the project	2	50.0%
CURI	Expressing curiosity or interest	1	25.0%
PERS	Persisting or persevering through obstacle	0	0.0%
LPERS	Lack of persistence or perseverance	1	25.0%
PRIDE	Expressing pride	0	0.0%
GOOD	Desire to do well	0	0.0%
FAC	Being factitious/ flippant	0	0.0%
	Who was involved		
TEA	Another teacher or educator	6	54.5%
OTH	Other Students	5	45.5%

However, their engagement was not a sustainable one. They would stop working when they reached a point where they had finished. This suggests that their interest only went so far as they would not seek out other opportunities to understand how we could use the sun and moon to tell time. This is also seen in their lack of discussion on any other project ideas and their quick dismissal of understanding other students' ideas. Thus their interest seems more focused on sundials overall rather than the topic itself.

4.2.3. Summary of Strand 1 Results

On the Likert-style surveys, there was a strong trend toward students agreeing or strongly agreeing with the Likert-items related to interest and excitement. This suggests a strong example of students' interest and excitement being sparked. Additionally, no students disagreed to any extent with items specifically linked to the planetarium visit during the curriculum. This suggests that the planetarium visit itself played a large role in sparking the positive results regarding this strand. This result is consistent with expectations of informal environments as they are expected to spark interest and excitement to a greater extent than formal classroom environments (National Research Council, 2009, 2010).

Engagement observed across the four groups studied was also consistent with students who are interested and motivated to learn, again suggesting that students' interest was sparked by the choice-based projects. Students were frequently on-task working on their projects. Groups exhibited deep level discussions about how their projects worked, asked thoughtful questions to make sure they understood why their idea could work, took initiative by working outside the classroom and setting up meetings to discuss idea on the phone at home, sought help from their teacher when they weren't sure how to best proceed, exhibited self-regulatory strategies, and did not allow their disagreements and challenges to stop them from creating projects. Students also exhibited curiosity by asking questions about astronomy, randomly stating facts they found interesting, wondering what would happen if they changed aspects of their project or by discussing other people's projects and how they worked. All of these are consistent with students that are interested and motivated to learn (Hidi, 2000; Renniger, 2000; Schunk et al., 1996).

Though these types of engagement were frequently noted, there were some marked types of engagement that suggested that some students were not engaged or interested. Specifically, students had periods of off-task behavior, with one student even napping at one point. Some students focused on how easy their project was to do, suggesting they were more motivated by external factors such as grades than the topic itself. However, these were often seen concurrently with more positive forms of engagement, and do not rule out student interest.

One group, however, seemed to struggle more than the others in working on their project. They focused more on surface level tasks such as decorating their project. While working they were frequently heard discussing off-topic things such as television shows. They admitted in a survey question that they did not understand the projects and it was their least favorite part of the unit. This was also seen in their work as they struggled to come up with a coherent idea of what to do and ignored advice given to them on how to improve their projects. Social dynamics seemed to affect their engagement when a dominant group member dismissed her partner's ideas. Despite there being several clear examples of behavior consistent with interest and excitement, there were some serious counter-examples that need to be considered as well.

4.3. Strand 2: Understanding Scientific Content and Knowledge

The results are presented by topic the students were asked about. I present the 1-2 most common levels of accuracy for student descriptions in the pre-interviews with 1-2 examples for each. Examples were chosen for their clarity and to highlight any differences that emerged within an accuracy level. This will be repeated with post-interviews with a short discussion after each topic.

Excerpts from the interviews will be used to illustrate ideas and descriptions from students. The interviewer will always be indicated as "**I:**" while various students will be indicated as "**S:**". Some answers from students within their interview are scattered across different parts of the interview (e.g. they discussed seasonal changes 2-3 different sections of the interview, they brought up information spontaneously at different points in the interview). Jumps in the transcript between relevant parts are indicated with "……". Inaudible portions of the interview indicated in written notes (e.g. hand motions) will be indicated in *(italics)*. Finally, if a key piece of information is needed that is not present in the transcription, such as the season a student is talking about, I will indicate this information in the transcript as [such].

4.3.1. Diurnal Path of the Sun

This topic considered whether or not students could describe the sun's motion as a continual arc from east to west. Students were considered to have complete and accurate answers if they described this key concept, even if they made other mistakes such as stating the speed of the sun's motion changed or it went through zenith, as these were addressed in other topic areas. Mistakes about where the sun's path was tilted, however, were noted, as this is specific to the diurnal path.

Pre-Interviews

All the students stated the sun had some form of motion in the sky. The completeness of that description differed and was originally coded in the accuracy level rubric. Most students gave either a semi-complete or completely accurate description. Semi-complete would be considered level 2 in the rubric where students correctly stated either how the sun moved or where it rose and set in the sky, but not both. A complete description is level 4 where students did state the sun rises in the east, sets in the west, and moves in an arc shape across the sky.

Level 2 - Semi-Complete Description of the Sun's Motion

Several students (N=3) had a semi-complete description of the motion of the sun in the sky. Tammy illustrates this clearly:

L1. **I:** Does the sun appear to move in our sky at all?
L2. **S:** Um, no.

I: Okay. So, where does it go at night then?
S: Well, it se—it sets...the sun sets at night. But in the...during the day it doesn't seem to move.
......
I: Okay. Okay. And can you describe where the sun was this morning when it rose?
S: Um...I don't know [chuckles].
I: Okay. You don't know? And that's okay.
S: Okay.
I: Can you predict where the sun will be at lunchtime today?
S: Um, it's probably going to be a little closer to our heads...
I: Okay.
S: ...than it is at night.
I: Okay. And how do you know that?
S: Um, because the sun is constant—the earth is constantly moving, and around the sun, with all the other planets. And so, um, it's going to...it has to set somehow. And if it sets like in the west, well, then it'd have to get closer and closer to the west throughout the day, so, it can actually set.
I: Okay. And can you predict where the sun will be at the end of the school day today?
S: Really close to where it sets [chuckles].
I: Okay. So how do you know that?
S: Um, because, like I just said, it keeps moving and moving throughout the day, so it has to be really close to where it sets.
I: Okay. And can you predict where it will set today?
S: Um...I think in the west. It's either the south or the west, I think.

Tammy is able to explain that the sun does move continually through the day, moving toward where it will set (L17-L18). She also mentions a difference in altitude when she explains that sun will be "closer to our heads" (L12) at lunchtime, showing some idea of an arc motion. However, she also states it does appear to set, but the sun does not seem to move during this day (L2-L5). This at first seems inconsistent with her explicit mention of how the sun moves continually later in her interview (L24). However, this statement of the sun not seeming to move could be that the sun does move slowly in the sky, but we never perceive its motion. So these statements may not be inconsistent.

As for the rise and set positions, she states explicitly she does not know where the sun rises (L7-8). She does state west as a possibility for setting, but is unsure and also offers south. She also adds in an "I think" showing, she is not entirely confident about where the sun rises and sets (L26-27). Tammy describes aspects of the sun's motion consistent with it moving continuously through the sky in an arc. However, she does not correctly state the rise and set directions of the sun, suggesting a semi-complete idea for the sun's motion.

The other two students at this accuracy level stated the sun rises in the east and sets in the west but did not correctly describe the motion of the sun in between. As one example we will look at Jessica who inconsistently explained the motion of the sun.

I: All right. And so first of all, does the sun appear to move in the sky at all?
S: Mmm, when the sun is going down, yeah.
I: Okay. So when the sun is going down. And can you describe how it moves?
S: It moves in a clockwise...counterclockwise motion, I guess.
......
I: [Coughs] Excuse me. All right. And can you describe where the sun rose this morning?
S: Um, in the east, I think.
I: Okay. And can you predict where it will be at lunchtime today?
S: Um, probably in the west.
I: Okay. Where in the west?
S: Um...not sure, just probably west.
I: Okay. And how do you know that?
S: Um, well usually the sun comes in the north, then east, then south. North to east, then in west probably. Actually, it'll probably be in the north. Probably in the north.
I: Okay, in the north? Okay. And can you predict where the sun will be at the end of the school day today?
S: Probably northeast.
I: Northeast, is that what you said? And why do you think that?
S: Um, because the sun comes down about where we leave, like 3:45, so...
I: Okay. And can you predict where the sun will set today?
S: In the west.
I: Okay. And why do you think that?
S: Um, I'm not sure. I just predict it's in the west.

Jessica described the sun's motion in a way that could be interpreted as an arc or at least circular motion when she suggests it moves in clockwise or counterclockwise (L4). However, her answers later describe a chaotic and inconsistent motion for the sun. For instance, she states the sun rises in the east (L7) but later says it starts in the north and then goes to the east (L13 – L14). She also explains that the sun will at some point be seen in each of the cardinal directions. This mixed with several uses of non-committal language such as "probably" and "I think" suggests she is not really sure in her answer. This could be a result of her not having a clear idea of the sun's motion. Alternatively, it could be she does know generally how it moves owing to her clockwise comment, but doesn't quite understand how directions work. Overall, she does not accurately or completely describe the sun's motion.

When asked specifically about where the sun rose and set, she did say east and west with less confusion attached, though with some non-commitment. However it is unclear why she thinks that.

The final student in this category explicitly stated that he heard the sun rises in the east and sets in the west from someone. However he simply answers, "I don't know" when probed about how the sun moves across the sky. These students are correctly describing one component of the sun's motion, but lack confidence in their answers or readily admit they do not know the other component.

Level 4 - Complete Description of the Sun's Motion

Of the ten students interviews, N=5 showed a more accurate description of the sun's motion in the sky. Below are two examples that illustrate this level of accuracy.

Kevin accurately described the motion of the sun in the sky. At times he seemed to confuse what he was trying to say, but did eventually come back to correct answers:

I: ...okay? All right, so I want you to think about the sun in the sky as we see it from earth, okay? So does the sun appear to move across the sky at all?
S: Uh, yes. Like when you're in a car, it kind of moves with you.
I: Okay.
S: With you.
I: What if you were standing still?
S: Mm, it doesn't look like it does.
I: Huh?
S: It doesn't look like it.
......
I: Okay. Good. And can you predict where the sun rose this morning, or describe where the sun rose this morning?
S: Uh...well, if it sets in the east...so it sets in the west, so the east?, I think. Yeah. *(arcing hands)*
I: All right. Did it rise exactly east?
S: Uhh...southeast? Yeah, southeast because...
I: Okay. All right, and can you predict where the sun will be at lunchtime today?
S: Ah, right in the middle of the east and the west, it'll like appear because it's the middle of a day. *(arcing hands)*

L20. **I:** Okay. And why do you think that?
L21. **S:** Because it's the middle of the day. And when it comes up in...in the morning, it sets...it's
L22. in the east. And then by night it sets in the west. So, it's the middle, so it might be in the
L23. middle.
L24. **I:** Okay. Can you predict where the sun will be at the end of the school today?
L25. **S:** West.
L26. **I:** Okay. The west. And can you predict where it will set today?
L27. **S:** Um, it would set in the we—so like at the end of the day?
L28. **I:** Uh-huh.
L29. **S:** At the west.

Kevin clearly states that the sun rises in the east and sets in the west. However, when asked about where the sun rises, he does stumble slightly first stating the sun sets in the east before saying immediately after that it sets in the west (L13). Once settling on the sun setting in the west, he states the sun must rise in the east.

Kevin also gave answers consistent with the sun moving in a continual motion from east to west. He arced his hands several times while he answered, suggesting he holds an idea that the sun moves in an arc shape throughout the day. He also states this more explicitly when he reasons through why the sun needs to be in the "middle" of the sky (L21-L23). He does explain at the beginning that the sun does not appear to move, however, this could again be the sun moves too slowly to notice.

Kevin correctly describes where the sun will rise and the set and that it moves in a continual arc shape, as suggested through his hand motions. This shows a more complete idea of the sun's motion.

Another student, Kelsey, offered a similar explanation to Kevin, but was a bit more explicit in expressing her ideas:

L1. **I:** Does the sun appear to move in the sky at all?
L2. **S:** Um...sometimes like when it's going up and down, when it's coming up, and in
L3. the sunset, it starts going down. And so... *(arcing hands)*
L4. **I:** Okay, can you describe how it appears to move?
L5. **S:** Um, well, it kind of moves in a...no...yeah, rotation. It comes up in the east,
L6. comes down in the west. And then it come—and then the next morning it comes up in the
L7. east, down in the west, and it just keeps like...it...you can't really tell if it's moving but
L8. it's moving like just a little bit.

......

I: All right, and can you describe where the sun was when it rose this morning?

S: About...well, it's east, about...I left my house...is about...I couldn't really see, I'm guessing about here. *(pointing low in the sky)*

I: Okay.

S: Because that's where it usually is when I walk out the door.

I: All right. And can you predict where the sun will be at lunchtime today?

S: Lunchtime, um, probably, um...like 12:00-ish?

I: Um-hum.

S: Yeah? Okay. Um...yeah, like kind of a little past halfway. *(pointing almost to zenith)*

I: Okay. All right, and how do you know that?

S: Um, well...ah, I know the days are shorter in winter. But I'm just going to use the summer as an...to explain. Like the summer, when I'm out a lot, I can see...because I'm usually up around 6 to go to my friend's pool. It comes up here. And it...it's like pale out. And it doesn't exactly look like the sun yet, until it gets about 9 o'clock, and it's like...or 8 o'clock. And it's higher up. And you can actually see it.

I: Uh-huh.

S: And then it...it keeps like going over, until it's a sunset again.

I: So, how about during the winter at lunchtime, does it have that same path that you just described?

S: Um, I'm pretty sure.

I: Okay. And can you predict where the sun will be at the end of the school day today?

S: Probably...the winter days are shorter. It gets dark at 6. So, about right...like here *(arcing hands, pointing low in the sky)* . It's like…yeah.

I: All right. And can you predict...actually how do you know that's where it'll be?

S: Um, well, I do know that the sun comes up in the east, and comes down in the west. From where I'm sitting, that's the west. So, um...yeah, because the west is...And the...the days are shorter in winter, so, the sun is going to go a little quicker down. And the moon is going to come up a little earlier than what it usually does.

I: Uh-huh.

S: So it's going to be a little closer down than what is usually would be.

I: Okay. And can you predict where the sun will set today?

S: [Short pause] In the west. Um, like...ah...um, I'm sorry, I don't understand you.

I: So where does...where will the sun set at the end of the day?

S: At...in the west. Um...

Kelsey explicitly states that the sun rises in the east and sets in the west when asked about how the sun moves (L5-8, L36-L37). She also says the same thing when asked specifically about rising and setting, showing consistency in her answers.

Similar to Kevin and other students, Kelsey arcs her hand when talking about the sun's motion (L3, L34), showing non-verbally an accurate description of the sun. Additionally, she explicitly states the idea of the sun moving continually when first asked about the sun's motion

(L5-8). This combined with the description the sun moves from east to west suggests a more complete idea as well.

Post-Interviews

The majority (N=7) of students gave complete descriptions in the post-interviews where they stated the sun moved from east to west in a continual arc. Three students stated some minor mistakes when explaining the motion of the sun (Level 3) while four students showed no mistakes (Level 4). The remaining three students gave either semi-complete or incomplete descriptions similar to those discussed in the pre-interviews.

Level 3 – Complete Description of Sun's Motion with Minor Mistakes

N=3 students at this level stated the sun moved from the east to the west in a continual arc motion. However, they also noted that in the middle of the day the sun was highest toward the north instead of the south. This was a source of confusion seen in the classroom as well. While giving presentations on sundials, several students became confused when their teacher asked them to turn where the sun would be in the sky. Many students stalled and turned toward the north. Below are two examples of students describing this idea.

Here is an excerpt where Tammy states correctly that the sun moves from east to west and in a continual arcing motion, but includes the incorrect idea of the sun being highest toward the north:

L1. **I:** Does the sun appear to move across the sky at all?
L2. **S:** Well, it doesn't appear to but it does move across the sky.
L3. **I:** Okay. Can you describe how it moves?
L4. **S:** It moves in a circular motion because the earth rotates, in a circle, around the sun. And so
L5. it...it, um, rises in the east and sets in the west.
L6. **I:** Okay. And how do you know that?
L7. **S:** Um, because in the planetarium we, ah...we stuck, um...where the sun rose each day, for
L8. like the first day of summer, the first day of, um, spring, and the first day of winter and fall. And,
L9. um, they all set in...they all rose in the east and set in the west, about...
L10. **……**
L11. **I:** Okay. And can you describe where the sun rose this morning?

S: It rose in the east.
……
I: Okay. And can you predict where the sun will be at lunchtime today?
S: Um, it'll probably be not above us but it's going to be the "middle-ish" of the sky...
I: Um-hum.
S: ...getting ready to go to the west, to set.
I: Okay. So what do you mean by "middle of the sky"?
S: Um, it'd probably be in the middle, in between east and west.
I: Okay. So which direction would it be?
S: It would be...well, that's north in our classroom, which means this is east and this is west. So it would about...about north.
I: Okay. And why do you think that?
S: Because it's the middle of the day.
I: Okay. And can you predict where the sun will be at the end of the school today?
S: It's going to be closer to west because it's getting ready to set.
I: Okay. And can you predict where it will set?
S: Um, well, if it's rising in the northeast, then it's going to set in the southwest.
I: And why do you think that?
S: Because it always goes in a complete circle. It doesn't like...it always goes in the full circle. It doesn't like kind of cheat and just go around half.

Tammy clearly states that the sun rises in the east and sets in the west and states that it moves in a continual circular motion (L5), suggesting an arc shape. Her answers are consistent asked specifically about the sun's rise and set positions (L12, L27-L28). When asked about the sun at different times of day, the positions she offers result in an arc shape. As a result she does display a complete idea of the motion of the sun as moving from the east to the west in a continual arc motion.

She does describe an inaccuracy in this motion in L30-L31 when she states that it has to go in a perfect half circle. She is essentially saying the sun will move to the exact opposite point in the sky, which only happens twice a year. She also states the sun moves in a path that is tilted toward the north (L21-L22). She also incorrectly attributes this motion to the Earth's orbit around the sun (L4), rather that its axial rotation. This is a clear misconception, however the cause of the motions was not addressed in this curriculum. If we look just at her identification of the sun's motion as rising in the east, setting in the west, and moving in a continual arc, Tammy does give a complete description. However, she also states incorrect details regarding the exact rise, set, and arc tilt positions, and the cause of this motion.

Garrett also described the sun's motion similarly, albeit with fewer mistakes than Tammy. This displays another way that students gave complete descriptions with minor mistakes:

L1. **I:** Does the sun appear to move in the sky during the day?
L2. **S:** Yeah, like probably hour to hour or something. Yeah, like twel—like...I
L3. remember making the sundial, like twel—like it would always move probably like hou—
L4. from an hour.
L5. **I:** Okay. And how does it move across the sky?
L6. **S:** What...it goes from the east to the, um...to the...rise in the east and go to the
L7. south, and sets in the south. *(arcing arms)*
L8. **I:** Okay.
L9. **S:** Or...or the west.
L10. **I:** Okay, so east to west?
L11. **S:** Yeah.
L12. **……**
L13. **I:** …can you describe where the sun is in the sky right
L14. now?
L15. **S:** Um...
L16. **I:** Well, I know it's cloudy, so use your best guess.
L17. **S:** Let's see here. Just got out of gym, so it's probably...probably like 10
L18. something.
L19. **I:** Yeah, it's about 10...
L20. **S:** Um...
L21. **I:** ...10:10 right now.
L22. **S:** So it's probably about like right there. Wait, you know, so that will be west. It's
L23. actually rightover...probably like right over there or something.
L24. **I:** Okay. So which direction is that?
L25. **S:** Um, that's east. I mean, no, it's northeast. Right. Yeah, I think it's northeast.
L26. **I:** All right.
L27. **S:** Yeah.
L28. **I:** So it's towards the northeast right now?
L29. **S:** Yeah.
L30. ……
L31. **I:** Okay. Okay, and can you describe where the sun rose this morning?
L32. **S:** Rose, um...gosh, I know I should have woke up earlier.
L33. **I:** That's okay. Where...
L34. **S:** Um...
L35. **I:** Where do you think it would have rose? Can you predict where it rose?
L36. **S:** Probably like, um, in the horizon. Um...yeah, just like a little bit of...a little...a
L37. little bit, um...there's only alittle bit of sunlight coming up from... Seems to get that it's
L38. partially blocked at the horizon.
L39. **I:** All right, in which direction?
L40. **S:** In the east.
L41. **I:** Okay. Exactly east?
L42. **S:** Well, the northeast, then...yeah.
L43. **I:** Okay. Is it pretty close to east?
L44. **S:** Pretty clo—um, yeah, it's pretty close to east.
L45. **I:** Okay. And can you predict where the sun will be at lunchtime today?
L46. **S:** Like right in the middle. *(pointing at about 50-60° in the sky)*
L47. **I:** Okay. And which direction is that?
L48. **S:** It's north.

L49. …...
L50. **I:** Okay. All right, can you predict where it will be at the end of the school day?
L51. **S:** No, I know it will probably like somewhere...we get out at 3:30, so, probably
L52. like right over there or something. *(pointing about 30° in the sky)*
L53. **I:** Okay. So which direction is that?
L54. **S:** Um, that is...um, that's northwest.
L55. **I:** Okay. And why do you think that?
L56. **S:** Um, I don't know, just thinking of the sundial, like it'll probably...at 3:30, on
L57. our sundial it was like right there. It was like right there when the sun was right there.
L58. **I:** Okay.
L59. **S:** So...so we could, um, really see it.
L60. **I:** All right, good. And can you predict where the sun will set today?
L61. **S:** Um, like right in the west, more like...ah, more like farther at the west than
L62. northwest but...[Speaks to someone else] Oh, bye, Mrs. Bernard. Um, yeah, probably a
L63. little bit more to the west than it...than ju—than at 3:30.
L64. **I:** Okay. And so why do you...why do you say that?
L65. **S:** Because, um, I remember, it doesn't...it doesn't...if...it's still in northwest when
L66. it...um, in northeast when it...um, when it...um, at dawn, it has, um...it ha—then it...when
L67. it sets it'll...it'll probably be a little bit more than, um, southw—um, a bit more than...no,
L68. not southwest, I mean northwest.

Garrett states that the sun rises in the east and then after first saying south, remembers that the sun sets in the west (L6-L11). He also shows continual motion of the sun first by arcing his arms when talking about the motion (L7). When asked about the sun's position at specific times, his stated positions result an arc shape showing consistency as well.

Despite having this more complete description, Garrett does display some mistakes. He states that the sun will be toward the North when it is higher in the sky during lunchtime (L47-L48). He states the sun rose slightly to the northeast, rose higher toward the north, and set toward the northwest. He seems to have misremembered the detail that the sun moves toward the south always in the Northern hemisphere. It could be he forgot, heard it elsewhere, or maybe saw something for the Southern hemisphere. The confusion could also have come from his project on a sundial (which he mentions) as sundials cast shadows in opposite directions from where the sun is. Overall, he does show a cohesive idea of how the sun moves, just missing details.

Level 4- Complete Description of the Sun's Motion Without Minor Mistakes

There were N=4 students that answered questions of the motion of the sun correctly and did not display any inaccuracies as Level 3 students. Walter gave a clear and complete description of the sun's motion across the sky:

I: So, I want you to think about the sun in the sky today. And I know it's cloudy, so imagine the clouds aren't there, okay?
S: Um-hum.
I: Does the sun appear to move in the sky at all?
S: Yeah, because like during...at noon it's...looks really high. And then when it sets, it looks really low. (*arcing arms*)
……
I: Okay. All right, and can you describe where the sun is in the sky right now?
S: Um, it's probably getting like...getting like right here, a little bit, than like...
I: Okay.
S: ...at the end because it's early in the morning...
I: Okay.
S: ...still.
I: And can you describe which direction that is?
S: And that would be, um, kind of more east.
I: Okay, good. And why do you think that?
S: Because it rises in the east and then it makes an arc over where it sets in the west.
I: All right, good.
S: And it just ro—rose almost, so...
I: All right, good. Can you predict where it'll be at lunchtime today?
S: Um, it'll probably be...because it's in the spring, probably going to be like right over here with like *[inaudible]* thing.
I: Okay. All right, and can you predict where the sun will be at the end of the school day today?
S: Um, it'll probably, um, be...probably be pretty low, getting ready to set, in the west.
I: All right. And can you predict where it will be when it sets?
S: It'll be west. And it'll be really cold.
I: Okay. Will it be exactly west?
S: Um...with spring, I think so, yeah.

First, Walter explains explicitly that the sun will rise in the east, set in the west and even states its path as an arc (L17-L18). He also consistently describes the correct positions in the sky for the different times of day. The only possible inaccuracy from Walter is that he is not asked specifically and does not state if the sun is in the south or the north at lunchtime. Thus it is possible that Walter does hold a similar idea to those students discussed as a level 3 above.

However, he does clearly give a complete description of the sun's motion moving from east to west in a continual arc.

Alexis also clearly stated the correct motion of the sun:

I: Does the sun appear to move across the sky at all?
S: Yes.
I: Okay. Can you describe that?
S: Um, it usually starts somewhere in the east. And then it usually goes over and sets somewhere in the west. *(arcing arms)*
……
I: All right, good. And can you describe where the sun is in the sky right now?
S: Um, it would probably be right around...hm. It would probably be like right around here, because it's going to be noon pretty soon. *(pointing E, midway up the sky)*
I: All right. So which direction is that, that you're pointing?
S: Um, east, sort of.
I: All right. Can you predict where the sun will be at lunchtime today?
S: It will be just about over there, right here by the like 30 or 40 point, in the south.
……
I: Um-hum. Okay. Can you predict where it'll be at the end of the school day today?
S: It will probably be right...it's getting later that it sets. So I would estimate right around like here, at the 20, 30 point.
I: Um-hum. In which direction?
S: In the west.
I: Okay. And can you predict where it'll set today?
S: It will probably set like sort of a little bit away from southwest, and closer to west.
I: Okay. And why do you think that?
S: Because, um, it's not winter but it's also not quite spring. It's getting away from winter. So, it would probably be like around...so say this is where southwest is, it would probably be around here if this is west. *(pointing southwest)*

Alexis states explicitly that the sun will rise in the east and move over to the west while moving her arms in an arc shape (L4 – L5). This shows am accurate description of the sun's motion in an arc from the east to west. When asked specifically about different times of the day, she also clearly explained how the sun first gains in altitude and then lowers. She even does this with explicit numbers in altitude. She also explicitly states that the sun is toward the south when near it's highest point (L12-L13). Alexis gave more specific details about the motion of the sun than other students that were all correct.

Summary of the Sun's Path

Though there were several students who had complete explanations in the pre-interviews, there were some notable differences in the post-interviews. First, students in the pre-interviews expressed less confidence in their answers, using statements such as "I think." In the post interviews, this was not noted, suggesting the students were more confident in their ideas. Additionally, in the post interview more students were able to correctly describe the larger idea of the sun appears to move in a continual arc from east to west, sometimes relying on arcing hand motions to help illustrate their ideas.

Some students did introduce incorrect details associated with this motion. One mistake student made included stating the sun would reach its highest point in toward the North rather the South. This is incorrect for the student's location and this mistake was seen while students worked on projects as well, despite students discussing the sun always being toward the south in both the planetarium and pre-activities. Another mistake seen was students stating the sun would have to rise and set on opposite sides of the horizon, which only happens twice a year. This implies students did not have a completely correct idea of how sun the moves in tilted arcs in the sky.

4.3.2. Altitude of the Sun

This topic looks specifically at whether or not students could explain that the sun never goes through zenith. Equatorial latitudes where the sun can go through zenith were not covered. Students were asked about the sun's apparent height in the sky at several points throughout the year and so answers were also considered when checking for accurate descriptions.

Pre-Interviews

A majority (N=8) of students suggested in the pre-interviews at some point that the sun did not go through zenith. However, half of those students were very inconsistent about how they talked about the sun's height or stated it went through zenith only some of the time (Level 2). The other half said it would never go through zenith (Level 4).

Level 2 – Inconsistently Says the Sun is at Zenith

N=4 students stated the sun sometimes goes through zenith. For 3 of these students, they consistently stated that the sun went through zenith when asked about the sun at lunchtime during different seasons. However, they also stated differences in height depending on the season, suggesting the sun does not always reach zenith. Lucas is a clear example of this inconsistent description:

I: Okay, good. And how high does the sun appear to get?
S: Um...
I: Think about the sun today.
S: Hm. It's just probably...hm. A few billion feet high.
I: Okay. So when we see it from earth, does it look like it's close to our ground, or does it look like it's right above our head, or somewhere in between?
S: Right above our head.
……
I: Okay. Okay. And can you predict where the sun will be at lunchtime today?
S: Probably around...or probably just like straight up and down from...bird, like this. Like if you look straight up, you can see the sun.
……
I: All right, so how high does the sun appear to get during the summer?
S: It appear—I think it gets a...when I look at it, it seems like it's higher than when it's in the winter.
….
I: Okay. And can you predict where the sun will be at lunchtime in the summer?
S: Probably the same as in the winter, straight up and down.
……
I: Now, how high does the sun appear to get during the fall?
S: Um, not as high as it would in the summer but not as low as the winter, so probably in between.
……
I: Okay. And can you predict where the sun will be at lunchtime in the fall?
S: Probably straight up and down again.

Lucas states on several occasions that the sun is “straight up and down”, suggesting the sun is at zenith when asked about how high the sun will appear at lunchtime for the day of the interview, the summer and fall (L10, L18, L25). He also states it will be right above our heads when asked how high the sun will appear for the day of the interview (L7). These descriptions alone suggest the sun consistently goes through zenith. However, he also states that the sun is higher in the summer than the winter (L14-L15) and the sun appears higher in the fall than winter but lower than the summer (L21-L22). These statements suggest the sun’s apparent height does change, which is inconsistent with his other descriptions.

One other student also displayed inconsistencies with the height of the sun as well, but not in the same way. Kelsey said for multiple questions that the sun would be at zenith, but also said during other questions it would be lower than the zenith:

I: Okay, good. And how high does the sun appear to get? So think about the sun today. How high does it appear to get in the sky?

S: Um...I’m not sure. Um, how high? Like...you...how do you...how do you want...like me to answer the question?

I: So, at its highest point, does it look like it’s kind of close to the ground? Does it look like it’s right above our head or does it look like it’s somewhere in between?

S: Um, in the middle of the day it looks like it’s like above you. And like when it gets closer to night, it looks like it’s like sitting on the ground, um, before it disappears. *(pointed at zenith)*

……

I: Okay. So if we think about it again in terms of does it look like it’s close to the ground, above our head, or somewhere in between, how high does the sun appear to get in the summer?

S: Um...

I: What’s the highest point it would get to?

S: A—above my head.

……

I: Okay. And so where will be...where will the sun be around lunchtime in the summer?

S: Um, it will probably be above my head, a little more this way, so like right here, um, a little south. Because I know it...it stays, um, like...‘til like 8, so...

……

I: All right, so how high does the sun appear to get during the fall?

S: Um...well, when...when I’m out at recess, around 12, you know, um, it seems to be a...a little farther than halfway, but not...not by much. Like instead of here it’s like here. It’s closer west because it’s getting closer to having the days and shorter than longer in the summer.

I: All right, so how...how high does it look when it’s at that point? Does it look like it’s sort of closer to the ground, right above your head, or somewhere in between?

L30. **S:** Um, somewhere...um, somewhere in between.
L31. ……
L32. **I:** Okay, good. And can you predict where the sun will be a little later in the
L33. morning, in the sky, in the fall?
L34. **S:** Um, probably like right above my head.

Kelsey says the sun will be above her head at several points in the interview (L7, L16, L20, L34), suggesting that it is at or very near to zenith. Inconsistency arises when she is asked about the apparent height of the sun during the fall. She states the sun will be between the ground and the point above her head (L30). Her description suggests the sun does not reach zenith, but she goes back to saying it would be above her head later that day (L34). It is possible she does not think it will go through zenith exactly as "above my head" is a rather vague statement and could include some altitudes that are close to but do not include zenith. However, even if she means those altitudes, it is much higher than the sun would reach at any point in her location.

Overall, students at this level show inconsistencies in how their descriptions of the sun's height. Where exactly these inconsistencies derive is unclear, but they do suggest room for improvement in their descriptions of height and altitude of the sun.

Level 3 – Consistently Says the Sun is Not at Zenith

N=4 students gave more correct descriptions of the sun never reaching zenith. However, across all the students they treated that zenith as a point where the sun *almost,* but does not quite reach. Walter gives a clear example of this:

L1. **I :** Okay. All right. And how high does the sun appear to get in the sky?
L2. **S:** Gets pretty high but not like at the top of what you can see.
L3. **I:** And what do you mean by top of what you can see?
L4. **S:** Like where...like as much up as you can see with your eyes.
L5. ……
L6. **I:** So think about when you're outside [in the summer]. I know you don't want to
L7. pay attention to the sun, but think about where you might have seen the sun in the sky,
L8. okay?
L9. **S:** Um, it's usually like right near the top and it's beating down on you with the
L10. heat and everything. So, it's usually like...like right above you, a little bit.
L11. ……
L12. **I:** Okay. And can you predict where the sun will be at lunchtime in the summer?

S: It'd be probably really high up. And it'll be really hot.
……
I: And how high does the sun appear to get in the fall?
S: Mmm, it's like in the middle, between that. Because, you know, it's starting to cool down a little bit, the whole earth and everything. So, it's kind of like in the middle.
I: Okay, what do you mean by the middle?
S: Like it's not exactly like...it's like noontime or close to it, but it's not like really hot or anything.
……
I: Um-hum. And where will the sun be in the sky at lunchtime [in the fall]?
S: Um, it'll probably be really close to where it is in the summer.
I: Okay. And how do you know that?
S: Because the fall is really close to summer in temperature and everything. So, it's just a little downward. So, it'll only be like a little...a little lower.

Walter consistently says the sun will get pretty high when asked about its altitude. He is also careful to say that it sun will be near the "top of the sky", but never quite that high (L2, L10, L23). At times when he does not specifically say near the top or near zenith, he uses vague terms like "really high" (L13), which suggests a point near but not directly at zenith. Therefore, Walter consistently states that the sun does not reach zenith, which is true for his location. However, he does say it gets near that point consistently, even for the day the interview was conducted in the middle of winter. So, though he is correct that the sun does not pass through zenith, he does not describe a completely normative idea on how high the sun appears to get.

Post-Interviews

In the post interviews, a majority (N=6) of studies moved to a normative description of the sun's apparent height in the sky, stating that the sun will never go through zenith (Level 3). The remaining 4 students gave inconsistent descriptions (Level 2) similar to those in the pre-interviews.

Level 3 – Consistently Says the Sun Never Goes Through Zenith

With the students who explained the sun never goes through zenith, they clearly stated this fact when first asked about how high the sun reaches. This was seen across all 6 students at this accuracy level. They also talked about the sun's altitude in more specificity than before by using numbers (presumably in degrees) to explain the altitude of the sun. One example of this is Lucas:

L1. **I:** Okay. And how high does the sun appear to get?
L2. **S:** Mm, at the highest, 75 degrees.
L3. **I:** Okay. And how do you know that?
L4. **S:** Um, because when we were in the planetarium, um, the sun never gets to 90
L5. degrees. It got to its highest point in the first day of summer.
L6. ……
L7. **I:** Okay. Good. And can you predict where it'll be at lunchtime today?
L8. **S:** It would maybe be...like if you looked up, you would see it. But it's not exactly
L9. at its...at, um, 90 degrees. So it's not exactly straight up and down. But it looks like it.
L10. ……
L11. **I:** And think about the sun then. So how high does the sun appear to get in the
L12. summer?
L13. **S:** It doesn't...um, it gets high but not 90 degrees.
L14. **I:** Okay.
L15. **S:** It gets like in between 70 and 80, maybe around 75 degrees.
L16. **I:** Okay. And how do you know that?
L17. **S:** Because when we were in the planetarium we did like winter, spring, and fall.
L18. And then summer was the highest out of all of them.
L19. ……
L20. **S:** Um...um, because, um...um, it...in the planetarium, I...I sort it sort of in the east.
L21. **I:** Okay. Good. And can you predict where it'll be at lunchtime in the summer?
L22. **S:** Um, yeah. It's probably the highest point, 75. But it's not exactly straight up, but
L23. 75, so it's close. So it looks exactly straight but it's not actually
L24. **……**
L25. **I:** ...okay? And so how high does the sun appear to get during the fall?
L26. **S:** It gets maybe around, um, the highest point, maybe around 60 or 65.

Lucas refers to zenith throughout the interview as "90 degrees", which is the correct altitude in degrees for zenith. He explicitly states throughout the interview that the sun would get close to 90, but not quite (L4, L8, L13). He even makes reference to the fact it may look that high, but it really is not (L9), suggesting why people may think it does reach zenith.

When describing the altitude of the sun in different seasons, he consistently uses degrees to explain this. He uses this for the fall and spring, incorrectly saying the sun gets to about 60 to 65 degrees (L26), when it is closer to about 48 degrees. However, he does describe the altitude as consistently lower than zenith in all case. This use of numbers to explain the altitude is seen in several students, across the different levels of accuracy as well.

Summary of Altitude of the Sun

In pre-interviews, several students gave answers that were inconsistent from a normative idea of the sun's altitude. Some students would state that the sun would reach different altitudes depending on the season, but also state that it would reach zenith at lunchtime for each season. These answers are inconsistent with one another showing some students did not have a very coherent view of the sun's altitude. Other students would consistently state throughout the interviews that the sun would not reach zenith. However, these students also consistently stated that the sun would get very close to zenith, suggesting that the position is just not precise. This is still a non-normative idea as the sun only gets relatively close to zenith around the first day of summer (about June 21^{st}) for their location.

In the post-interviews, there was a clear move in student answers toward consistently stating the sun does not reach zenith. Furthermore, rather than just having consistent answers, students would make it a point to clearly articulate that that the sun could not reach the zenith. There were also consistent answers from students stating clearly that the sun would be significantly lower than zenith at some points in the year rather than always being close but not quite there. This suggests that students shifted their ideas toward a more normative idea regarding the sun's altitude for their location, consistently stating the sun does not go through zenith and it rarely even gets close.

Finally, in post-interviews, it was noted that students would use correct degree markings from the meridian marker projected in the planetarium show to describe the sun's highest altitude for each season. This suggests that students were using the visual aids in remembering key details. Additionally, it suggests students were using the planetarium show, as a source of knowledge and utilizing it several weeks after the visit and therefore the planetarium visit itself was a useful addition to this curriculum.

4.3.3. Seasonal Changes of the Sun's Motion

This topic looks at whether or not students could describe that the sun's exact rise and set position and highest altitude changes throughout the seasons. Student accuracy in describing the correct rise position, set position, and altitude of the sun were also checked. The cause of the seasons was not addressed in this curriculum and thus not studied.

Pre-Interviews

Students gave very inconsistent and incomplete descriptions on how the sun's path changed through the year. A majority of students (N=6) stated the sun reached higher altitudes in the summer than the winter without also stating the sun rose and set in different locations (Level 2). Students in this category also showed a great deal of inconsistency in their description of the height.

Level 2 - Incomplete and Inconsistent Description of Seasonal Differences

Alexis shows a clear example of both incomplete descriptions regarding the directions of the sun's rise and set position as well as some inconsistency in the differences in the sun's altitude. First, I will show her description of where the sun rises and sets between summer and fall:

I: Okay. Good. And can you describe where the sun rose this morning?
S: Um, it rose in the...forget, is it east or west? I think it's the east. And, um...yeah, I think it rises in the east. And then it pretty much just looks like a yellow thing, rising up into the sky.
……
I: Okay, good. And can you predict where it'll...where it will set today?
S: In the west, probably, like over at the end of the town.
…….
I: Okay. And can you predict where it'll rise in the summer?
S: It will rise in the east.

L11. **I:** Okay. Exactly east?
L12. **S:** Well, it's probably not exactly east but it's east.
L13. **I:** Okay, and how do you know that?
L14. **S:** Because we...the compasses aren't really quite exact. So, it'll look...it'll look like it's
L15. east...
L16. ……
L17. **I:** And can you predict where it'll set in the summer?
L18. **S:** It will set in the west.
L19. ……
L20. **I:** Okay. And can you predict where the sun will rise in the fall?
L21. **S:** Um, it will rise in the east.
L22. **I:** Okay, and how do you know that?
L23. **S:** Because it always rises in the east.
L24. **……**
L25. **I:** All right, and can you predict where it'll set [in the fall]?
L26. **S:** It will set in the west.

Alexis clearly states that the sun rises in the east throughout all the seasons (L3, L7, L15) and it will set in the west (L7, L18, L26). However, she makes no distinction between the precise directions for each season. This was seen with several students. Some students simply did not answer where the sun rose and set. Though the sun does always rise in the east and set in the west, it is toward the northeast/northwest in the summer and southeast/southwest in the winter. The difference is drastic. Alexis clearly does not state these differences and it is possible she does not know there are significant differences.

Next we can look at Alexis's descriptions of the sun's height through the seasons. During her interview she states at one point the sun's height is different between the seasons:

L1. **I:** I'm sure you're not paying attention to the sun but, you know...all right? All right, so
L2. high does the sun appear to get in the summer?
L3. **S:** It usually appears to get higher than it does in the winter...

She says the sun is higher in the summer than the winter, which is correct. However, later she states specifically that there are no differences between where we see the sun in the sky during the seasons on two different occasions:

L1. **I:** Okay. And is there a difference between where we see the sun in the sky between the
L2. winter and the summer?
L3. **S:** Um, well, not really, actually.
L4. ....
L5. **I:** Okay, is there a difference between where we can see the sun in the sky between the

L6. winter and the fall?
L7. **S:** Um, no, not really.

She does say "not really" on both occasions, suggesting the differences might be there but are not of great significance. However, she explains there are no real differences after saying there is an explicit difference in the height. Furthermore, when asked about the sun at specific times of day (particularly lunchtime) for the different seasons, she explained:

L1. **I:** Okay. And can you predict where the sun will be at lunchtime today?
L2. **S:** Probably in the center of the sky. *[she explains elsewhere that center is essentially zenith]*
L3. ……
L4. **I:** Okay, good. And can you predict where it'll be at lunchtime in the summer?
L5. **S:** Usually at lunchtime it's still around the center of the sky.
L6. **I:** Okay. So, what do you mean by "center of the sky"?
L7. **S:** Like, um, up high and like not quite...it's like north but up in the center. *(pointing at zenith)*
L8. **……**
L9. **I:** Okay. And how about at lunchtime [in the fall]?
L10. **S:** Lunchtime it's usually around the middle of the sky.
L11. **I:** Okay, and how do you know that?
L12. **S:** Because, um, sometimes...like when we go outside for recess, then I look up and...

Alexis is saying the sun still reaches zenith or near zenith around lunchtime in each season. Despite saying the sun reaches different heights, she does not consistently describe this elsewhere. This kind of inconsistency could be from a disconnected view of how the height of the sun works. The students could also have learned this before and are parroting the fact without a normative idea as to what it means.

Some students were not inconsistent, but still incomplete in their descriptions of height differences and not in rise and set positions. The two students who showed this type of incompleteness did not clearly describe the altitude of the sun at different times of the day. So it is possible they also had inconsistent views, but there was no evidence in their interviews. To show this, we will look at Kevin beginning with the directions:

L1. **I:** Okay. Good. And can you predict where the sun rose this morning, or describe
L2. where the sun rose this morning?
L3. **S:** Uh...well, if it sets in the east...so it sets in the west, so the east?, I think. Yeah.

I: All right. Did it rise exactly east?
S: Uhh...southeast? Yeah, southeast because...
……
I: Okay. The west. And can you predict where it will set today?
S: Um, it would set in the we—so like at the end of the day?
I: Uh-huh.
S: At the west.
I: Okay. Will it set exactly west?
S: Um, no, probably like...probably like...maybe like east-west, southwest, something like that.
……
I: All right. And can you predict where the sun rises in the summer?
S: Umm...probably the east. No...yeah, east.
I: All right. And is it exactly east during the summer?
S: No, it's east...northeast, southeast, something, not like exactly east.
I: Okay. And how do you know that?
S: Um, because usually it's not like that direct, like right in the east, it's probably over...somewhere in the east but not right in the east.
……
I: Okay. And where will the sun set? Can you predict where it will set in the summer?
S: At the end of the day?
I: Yeah...
S: Ah...
I: ...at the end of the daytime.
S: ...down here in the west because of...because if it sets here, it would do a rotation. So, in the middle of the day it would be here. And at the end of the day it would be down here.
……
I: Okay. And can you predict where the sun will rise in the fall?
S: Um, east, east...east-west somewhere, not directly in the east but somewhere around east. And then it would set at night in the west.

Kevin consistently says the sun will rise in the east (L3, L16, L33) and set in the west (L10, L28, L34). He states the sun does not necessarily always rise and set exactly in those directions, but he does not connect this in any way to the season when probed further (L20, L34). This suggests, similar to other students and Alexis, that there is no seasonal dependence on the rise and set positions of the sun.

Kevin does state at multiple points that the sun will be higher in the summer than in the winter and the fall is somewhere between, again similar to Alexis and other students:

I: ...all right? How high does the sun appear to get during the summer?
S: Ah, higher during the summer because...it seems higher because you can see it. Like during the winter, sometimes you can't see it because it's all white. And it seems lower. But in the summer you usually can see it unless it's like raining, because it's usually blue sky.
……
I: … how high does the sun appear to get in the fall, or in the autumn?

L8. **S:** Um, probably...higher than winter but lower than summer. Like...yeah, higher
L9. than winter but lower than summer. Because it's in the middle of winter, it's winter so
L10. like...no. Yeah. Well...yeah. Winter, it would be lower in the sky. And then summer
L11. would be high. And then fall would be low again because at the end) of fall the time
L12. changes. So it's...the sun sets earlier than 9 o'clock, like 8:30, then it goes to 8. Winter
L13. time, you know, it'll be 6:30 again.
L14. **I:** All right. And is there a difference between what we see in the sun during the
L15. winter and the...sorry, during the winter and the fall time?
L16. **S:** Um, in the s—in the winter, it will maybe be higher because of the year-around.
L17. And it's closer to the new year than it...than the...uh...up in the fall is. So it might be hi
L18. —it be lower than autumn because of the year-around.

Kevin states first that the sun is higher in the summer (L2-L5) and that the fall sun is between where it would be in the summer and the winter (L8-13). In L16-L18 he seems to start contradicting himself but changes his answer back something more normative, suggesting he simply misspoke. In his explanation in L12-L13, he starts associating the length of day with the altitude of the sun. The sun's path length does change during the seasons, which results in shorter days and the sun's difference in altitude. He does not complete this line of reasoning, but he does show the start of a more sophisticated idea. However, his description is still incomplete without also clearly stating the different rise and set positions.

Post-Interviews

During the post interviews, a majority of students (N=7) gave more complete descriptions that included statements that the sun's rise and set positions were different along with descriptions consistent with an idea that the sun's highest altitude would change. However, many of the students seemed to miss details along the way or make other mistakes in their descriptions (level 3).

Level 3 – Complete Descriptions of Seasonal Differences with Some Mistakes

Two examples of students will be discussed. These students were chosen specifically to highlight some of the different inaccuracies that were exhibited. I will first look at Lucas, starting with his description of the sun's rise and set positions:

I: Okay, good. And can you describe where the sun rose this morning?
S: Um, it rose maybe in the, um, east. Because it moved to the southeast, and then it'll just go around. So, it probably rosed [sic.] in the east.
I: Exactly east?
S: Mm, probably not exactly. Maybe a little bit southeast, maybe.
……
I: Okay. And can you predict where it'll be when it sets?
S: Um, maybe a litt—maybe, um, west or southwest.
……
I: Okay. Can you predict where the sun will rise in the summer?
S: Um, maybe northeast.
I: Okay. And how do you know that?
S: Because, um...probably because, um, in the, um, planetarium, it rose sort of like around, um, northeast.
……
I: Okay. All right. And can you predict where it'll set in the summer?
S: It would probably set in the, um...probably in the west because it always sets in the west.
I: Okay. Will it set exactly west?
S: No, probably, maybe, northwest.
…...
I: And can you predict where the sun will rise in the fall?
S: It would probably rise in the...maybe east.
I: Exactly east?
S: Um, maybe a little southeast.
I: Okay. And why do you say that?
S: Because when we were in the planetarium we were looking, and you could see the sun rise in the different, um...um...um, seasons. And then, um we had put those signs up. So, um, it sort of looks like it's maybe like a little ea—um, southeast.
……
I: Okay, good. And how about at...how about, where will it set in the fall?
S: It would set maybe, um, a little southwest because the days aren't as long. So it's going to maybe set a little bit shorter than it would set in, um, the summer.
……
I: All right, good. And a quick question about the sun...a couple of questions about the sun in the winter. Where does the sun rise in the winter? Can you predict that?
S: Mm, maybe, um, east.
I: Exactly east?
S: Um, pro—maybe a little northeast.
I: Okay. How about, where will it set?
S: Maybe a little southwest because it's not...the days are not as long as summer, and fall, and spring. So it's going to be not that long, but it's still going to be maybe a little long. So it's going to maybe go not as long as summer and spring, so it's probably maybe going...so the sun won't be up as high.
……

L46. **I:** Okay. How about, where will it set?
L47. **S:** Maybe a little southwest because it's not...the days are not as long as summer,
L48. and fall, and spring. So it's going to be not that long, but it's still going to be maybe a
L49. little long. So it's going to maybe go not as long as summer and spring, so it's probably
L50. maybe going...so the sun won't be up as high.

On the day of the interview and for fall he says the sun rose a little southeast (L5, L25) and set a little southwest (L8, L32). The fall and spring paths are very similar in the sky, so it is not incorrect to say the sun rose in the same spot. However, for the first day of fall and spring, the sun rises exactly east and sets exactly west. Even if one talks about the sun on any day in those seasons, they should not be exactly the same position in the sky. For the summer he says the sun rose in the northeast (L11) and set in the northwest (L20), which is correct for summer. For the winter he states that the sun will rise in the northeast (L39) and set in the southwest (L47). It is correct that the sun sets in the southwest in the winter, but it rises in the southeast in the winter. It is possible that Lucas simply misspoke or he just does not remember the correct rise and set positions. Overall, Lucas clearly states that the sun rises and sets in different spots for the seasons, referring to the seasons directly for his answers (L33, L47) or to the visual aids marked by season in the planetarium (L27-L29). However, he does not quite have the correct directions yet. Not being able to correctly identify the directions by season, but know they change was a common theme throughout the interviews at this level.

Now, we will look at Lucas's descriptions of the height of the sun in the sky throughout the seasons:

L1. **S:** Okay.
L2. **I:** And think about the sun then. So how high does the sun appear to get in the
L3. summer?
L4. **S:** It doesn't...um, it gets high but not 90 degrees.
L5. **I:** Okay.
L6. **S:** It gets like in between 70 and 80, maybe around 75 degrees.
L7. ……
L8. **I:** Okay. Good. And can you predict where it'll be at lunchtime in the summer?
L9. **S:** Um, yeah. It's probably the highest point, 75. But it's not exactly straight up, but
L10. 75, so it's close. So it looks exactly straight but it's not actually.
L11. ……

L12. **I:** Okay. Good. And is there a difference between where the sun is during the
L13. winter and the summer?
L14. **S:** Um...um, yes, because, um, the sun gets higher. It gets to like 75. But in the
L15. winter it maybe gets around 30. So there's a big difference in between, um, how high the
L16. sun gets.
L17. **……**
L18. **I:** ...okay? And so how high does the sun appear to get during the fall?
L19. **S:** It gets maybe around, um, the highest point, maybe around 60 or 65.
L20. **I:** Okay. And how do you know that?
L21. **S:** Because in the planetarium it's not the highest. Like the summers are highest.
L22. But it's not the lowest, so it's maybe like sort of in between...
L23. **……**
L24. **I:** Okay. And is there a difference between where we see the sun in the winter and
L25. the fall?
L26. **S:** Yes, because, um, fall is...the sun's still a little higher than, um...than, um,
L27. winter because winter's around maybe 20 or 25. And fall's maybe around 60 or 65. So,
L28. there's a pretty big difference in between those two still.

Lucas states explicitly that the summer is when the sun is the highest, stating several times it will be around 75 degrees (L6, L9, L14) for altitude. He also states that in the fall the sun will get to about 60-65 (L19) degrees and to about 20 or 25 degrees in the winter (L27). This puts the sun at different highest altitudes in the correct order (summer at the highest, then fall/spring and then winter). His numbers for fall are slightly off as it really only gets to 48 degrees, but he still states the correct order with the sun at a mid-altitude. He also shows some consistency when asked about the sun at lunchtime in the summer, stating again it would be about 75 degrees (L9). This consistent description of height differences was seen across and accuracy levels. Furthermore, students were able to articulate altitude with numbers seen in the planetarium. This was not the intention of using the meridian, but it does seem that students were able to use the numbers as a tool to remembering altitude differences.

Kevin similarly mixed up details for where the sun would rise and set but stated the correct altitudes. However, he also displayed some different inaccuracies along the way. I will again start with his description of rise and set directions:

L1. **I:** Okay. And can you describe where the sun rose this morning?
L2. **S:** In the east, um, over here in the east. Not directly in the east but like...it's, uh,
L3. east but not "right smack" in the east.
L4. ……

L5. **I:** All right. And can you predict where the sun will set today?
L6. **S:** Um, it'll set in the west, probably the...little bit southwest but not directly in the
L7. west.
L8. **……**
L9. **I:** Okay. Good. And can you predict where the sun will rise in the summer?
L10. **S:** Um, still in the east, maybe a little bit earlier. It'll rise a little bit earlier, but still
L11. around in the east, northeast.
L12. **I:** So, the northeast? Okay. And how do you know that?
L13. **S:** Um, because if it...if it sets in the southwest. The opposite of that is the
L14. northeast.
L15. **……**
L16. **I:** Okay. And how about when it sets? Where will it set in the summer?
L17. **S:** Well, still in the southwest but maybe a little bit higher it'll set. Because it's the
L18. summer and not the spring.
L19. **…….**
L20. **I:** Okay. Good. And can you predict where the sun will rise in the fall?
L21. **S:** Um, I think in the s—for spring and the fall it'll be more to the northeast. Like
L22. in the winter it'll be in the northeast. And then in the summer it'll be a little bit more.
L23. And then like the spring and fall will be a little bit like down more.
L24. **I:** So which direction is that, that you're pointing at?
L25. **S:** Northeast.
L26. **I:** Northeast, okay. And so why do you say that?
L27. **S:** Um, because when we...because if it's a little...if I think...if it's a little bit higher
L28. in the summer and a little bit like kind of more acc—like higher in the summer, and then
L29. kind of like in the north...like in the northeast, like perfect...not perfect but almost perfect,
L30. in the winter, then maybe it'll be a little bit lower in the spring and, um, fall.
L31. ……..
L32. **I:** Okay. All right, good. And can you predict where it'll set in the fall?
L33. **S:** Um, like the north—like the northeast, it'll set a little bit lower than the, um,
L34. summer and winter. Because in the summer it'll do it like a little bit higher. In the winter
L35. it'll do low. And then in the spring and fall it'll be a little bit like lower.
L36. ……
L37. **I:** All right, and where does the sun rise in the winter?
L38. **S:** Um, I think in the northeast, like almost directly in the northeast but not like
L39. perfect.
L40. **……**
L41. **I:** And how about, where does it set?
L42. **S:** In the southwest, not perfect but pretty good, like in...

Kevin also says the sun rises in the east and sets in the west in most cases, with the exception of the fall (L33) where he says the sun will set in the northeast. During his interview there were points when discussing the fall where he arced his arms, suggesting he thinks the sun moves from east to west, suggesting that saying northeast may have been an accident. Kevin connects differences in rise and set positions to the season (L17-L18). This reference to other seasons suggests that seasons matter for rise and set positions and was seen with other students as well.

Though Kevin suggests the time of year factors into the rise and set position, he does not correctly state what those rise and set positions are for each season. For the day of the interview, he simply says the sun will not rise or set exactly in the east and west. He does suggest that the sun will set a little southwest (L6), which is correct, but he does not give a fully normative answer with the rise position as southeast. When discussing the summer, he does put the rise position at the northeast (L11), which is also correct, but then says it will set in the southwest (L13, L17). This puts the rise and set positions directly opposite from each other. Kevin even explicitly states this is the reason why he thinks the rise and set positions are at those positions (L13-L14). Kevin displays an idea seen with some other students that the sun must rise and set on opposite sides of the sky, which could explain some of his missed details regarding the sun's rise and set position.

Kevin's descriptions of the sun's altitude were consistent and correct for the seasons:

L1. **I:** Okay. And so let's think about the sun during the summer now, okay? So
L2. imagine we're outside during the summertime. How high does the sun appear to get in
L3. the summer?
L4. **S:** Um, higher than the winter, and spring, and fall because it's...I don't know why
L5. it does it but it's always higher in the summer.
L6. **I:** Okay. And how do you know that? How do you know it gets higher?
L7. **S:** Um [sighs]...mm, maybe because it's like out more, because in the winter it's
L8. kind of...it gets snowy and gets all like white. And in the spring it's rainy. And in the fall
L9. it's kind of like rainy too. So maybe it's out more, so it's more higher.
L10. ……
L11. **I:** Okay. And is there a difference between where we see the sun in the sky
L12. between now and the summer, or between the winter and the summer?
L13. **S:** Um, yeah, because the...in the winter, I think the sun's not out as much.
L14. And...but the summer is...is, so maybe it's maybe farther. Like at lunchtime in the winter
L15. it'll be like in the southwest. And then, in...lunchtime in the summer it'll be a little bit
L16. more to the south, and the middle...more to the west than the...than the sou—than the
L17. south.
L18. ……
L19. **I:** Okay. And can you predict where it'll be at lunchtime in the summer?
L20. **S:** Mm, probably almost the same place, maybe a little bit...a little bit more to the
L21. southwest, because it's the summer [coughs], not the spring.
L22. ……
L23. **I:** And let's think about the sun during the fall time now instead, okay? Let's think
L24. about that. How high does the sun appear to get in the fall?
L25. **S:** Um, not as high as the summer but not as low as the winter, so kind of like right
L26. in between.
L27. **I:** Okay. And how do you know that?

S: Um, because when we did our project, me and Peter said that the sun was at its highest point in the summer and its lowest point in the winter, and the spring and fall were right in the middle of s—of summer and winter.

…….

I: Okay. And is there a difference between where we see the sun in the sky between the winter and the fall?

S: Um, yes, I think because in the winter it's the sun is low. But in the spring and fall it's a little bit higher. And then in the summer it's big. Like it gets really high, the altitude.

……

I: Okay. And can you predict where it'll be at lunchtime in the fall?

S: Um, if the s—summer is like in the middle, like north—if it's in the southwest, and the winter...I mean, and the summer's a little bit like low...like more towards southwest. Then the spring might be a little bit like more in the northeast, like still.

I: Okay. All right, and so how do you know that?

S: Well, I think that in the summer it kind...the days go kind of more fast. But in the winter they're kind of slow. So, I think the s—winter will be right here and the spring will be a little bit lower at lunchtime. So, then the fall will be like less than the s—winter because, um...yeah.

Kevin correctly states that the sun is higher in the summer than the winter or spring/fall (L4) and that the fall/spring is in between the summer and the winter (L25, L29). He does not contradict himself anywhere with regards to the height. However, when asked about lunchtime, instead of talking about altitude he often talked about the direction the sun would be (L20-21, L39-L41). When asked why he thought this, he stated that the sun moves at different rates depending on the season (L43-L44). This inaccurate explanation was seen with some other students as well. Some students stated the sun will move at different rates and this results in some of the differences we see. The speed of the sun's motion was not explicitly discussed in the curriculum, but the teacher did briefly mention this was not the case in the classroom.

Kevin correctly describes that there are distinct differences between the seasons in terms of the sun's rise and set position and altitude. However, he does not correctly state details about the sun's rise and set position and displays other non-normative ideas regarding the sun's motion and seasonal differences.

Summary of Sun's Seasonal Differences

Similar to the students' ideas of the sun's altitude discussed in the previous section, students gave inconsistent answers regarding the sun's apparent height differences. Students would say the sun reached the same height at lunchtime for each season, but also state that it would be higher in the summer and lower in the winter. Students did study these topics in second grade at their school. It is possible that students are repeating facts they remember but not tying those facts to their other ideas of the sun's height. In the post interviews, they were more consistent, correctly describing how the sun's apparent height would change between the seasons and stating the correct numbers from the meridian degree marker from the planetarium show, showing a move toward normative ideas regarding that particular aspect of the sun's seasonal path differences.

In the pre-interviews, students did not state that the sun would rise and set in different positions. Some students would clearly state or imply the sun rose and set in the exact same position throughout the seasons. Students who did state the sun rose and set in different positions did not connect that idea to the seasons themselves, suggesting that there was some level of imprecision in how the sun appears to move. The post interviews, however, students did clearly state that the sun would rise and set in drastically different positions, sometimes referring back to the season we were talking about in their answer. This suggests that students again grasped the larger idea that the sun does indeed drastically change its rise and set position. Students did miss the details of the exact correct rise and set positions, not clearly stating that the sun rises and sets toward the north in the summer and toward the south in winter. This could be from simply misremembering what they saw in the planetarium or they could have stemmed from underlying incorrect assumptions such as the sun always rises and sets on opposite sides of the sky.

4.3.4. Motion of the Moon Through the Sky

This topic focused on whether or not students were able to state that the moon moves across the sky in a continual arc from east to west, similar to the sun. It did not look specifically at when this occurs, only that there is a diurnal component of the moon's motion.

Pre-Interviews

Generally the students gave completely non-normative (Level 0) or incomplete descriptions (Level 2) of the how the moon moved across the sky. Students were asked if the moon appeared to move in the sky at all. Those students who said it did not move were asked to explain where it went when we could not see it. This lead to varied incorrect answers. More students gave an incomplete description of the moon's motion by stating it did move continually, but only discussed this the moon's motion by moving to a bird's eye view of the Earth/Moon system, never describing how it moved from an Earth-based perspective.

Level 0 – Says the Moon Does Not Move

There were N=3 students who explained the moon did not move and each one gave different reasons why. I will look at two examples here of the more clear reasons students gave. First, Alexis stated the moon simply turns in the sky:

L1. **I:** So we're going to stop talking about the sun. Does the moon appear to move in
L2. the sky at all?
L3. **S:** What?
L4. **I:** Does the moon appear to move in the sky at all?
L5. **S:** Mm...well, no, actually, not really.
L6. **I:** Okay, so where...
L7. **S:** Not much.
L8. **I:** Where does it go when we can't see it then?
L9. **S:** It's really...it turns, and there's a dark side to the moon, compared to the light
L10. side. So then, when we can't see the moon, what we call a "new moon", it's...the dark
L11. side...

Alexis explicitly states first that the moon does not move (L5), but instead the moon rotates so a dark side faces us (L9-L11). During new moon, only the non-illuminated side faces us, so to some extent this is not a completely incorrect statement. However, she also links this to the idea of the moon turning in the sky. Her description suggests the moon sits in one spot in the sky and it will turn through its phases revealing different amounts of the illuminated side. This idea seems to build off of a more normative explanation of the phases of the moon, but it has been misinterpreted or misremembered by her in this instance.

Jessica also stated the that the moon does not appear to move in the sky and gave an entirely different, but also clear reason as to why she thinks this:

I: Okay, good. All right, and now it's the last two questions, okay? And I'm going to stop asking you about the sun over and over again. And I'm going to ask you about the moon instead, okay? So now think about the moon in the sky. Does the moon appear to move in the sky at all?
S: Mmm, probably...probably not.
I: Not really?
S: Not really.
I: Okay. So where does it go when you we can't see it then?
S: Uh, probably on the other side of the Earth...*[inaudible]* um, probably further away from the earth. And yeah, probably further away from the earth.
I: Okay, further away from the earth? All right, and how do you know that?
S: Umm...
I: We'll be done in a few minutes, okay? Sorry. *[to other students who want to sit where we are sitting]*
S: I'm not sure.

Here Jessica states that the moon probably does not appear to move (L5). When asked where it goes when we cannot see it she starts to say that it would be on the other side of the Earth, which is not entirely incorrect (L9). The moon will eventually be on the opposite side of the observer as the Earth rotates. However, she does not fully state this as a reason. She also modifies her answer to incorrectly say it will actually be farther from the Earth (L9-L10).

Level 2 – Says the Moon Will Move Continually from Space-based Perspective

Several students (N=5) stated rotation of the either the moon or the Earth when talking about the moon's motion. They often used descriptions as seen from a bird's eye view. However, these were also filled with non-normative explanations from the students. One example is Tammy, who misstated what was rotating in the sky:

L1. **I:** So, now think about the moon in the sky. Does the moon appear to move in our
L2. sky at all?
L3. **S:** Um, it does move but you can't really see it move unless you just watch it, and
L4. watch it, and watch it.
L5. **I:** Um-hum.
L6. **S:** But, um...
L7. **I:** So how do you know that?
L8. **S:** Because, um, the earth spins around the sun. And it goes in a circle while
L9. spinning. And so the moon kind of stays put. And it stays while the earth spins.
L10. **I:** Okay. And can you describe how the moon moves in the sky?
L11. **S:** It moves in a circle around the sun and kind of around the earth.

Unlike Alexis and Jessica above, Tammy states that the moon appears to move in the sky, albeit very slowly (L3-L4). When asked for why she thinks this she starts giving an explanation by shifting to a bird's eye view of the solar system. She correctly states that Earth revolves around the sun and it spins (L8-L9). She also says that the moon stays in one position as the Earth rotates. This is not true as the moon does also orbit the Earth. However, she does eventually say that he moon appears to move in a circle around the Earth (L8) suggesting she has some idea that the moon's motion in the sky is a continual arc but she does not also state that it goes from east to west, showing an incomplete description.

Kelsey also displays similar ideas with mistakes in her description. She explains the motion of the moon from a different perspective and offers a possible explanation as to why this form of explanation was so prevalent:

L1. **I:** Okay, so does the moon appear to move in the sky at all?
L2. **S:** Um, at night I do think it moves. But you can't really tell that it's moving. So...
L3. **I:** How does it move? Can you describe that?
L4. **S:** Um, well, the s—the sun...oh, that's *[inaudible]*. Um, the...I know the sun has
L5. something to do with it. Um, it's like it...it's like a push and pull. Um, so when the sun
L6. goes down, ah, automatically the moon goes up. And when it starts coming down, the sun
L7. comes up. So it's like a rotation.
L8. **I:** Uh-huh.
L9. **S:** I do think the sun has something to do with it. I'm not sure what.
L10. **I:** And how do you know that?
L11. **S:** Um, I do remember some of the classes that I had a while back, uh, in like
L12. second grade, where he talked about the push and pull of the moon and sun, how they

L13. work together to like move around.
L14. **I:** Okay. And so in describing this motion with the sun and the moon, does the
L15. moon always set when the sun comes up, and rise when the sun goes down?
L16. **S:** Um, no, it's like, um, the...so when the sun goes down, um, you can...(? 21:11)
L17. the moon goes up when the sun's setting. And then it kind of moves. But the sun doesn't
L18. go f—moon doesn't go fully down when the sun comes up because you can sometimes
L19. see...I'm not [sighs]...you can sometimes see like the moon. But I remember that...I can't
L20. exactly remember what...whether it was the moon or it was a reflection of the moon. I
L21. can't remember. But I know it was something like that. So, that's...so it doesn't exactly
L22. go down like exactly. But I know like when the sun comes up here, it's more...it's more
L23. down. You can't really see it. But you...you can see like a shadow of it or something.

Kelsey states that she thinks the moon moves (L2) but also puts on the qualifier that the movement is difficult to notice. Similar to Tammy, she connects the movement of the sun to the idea of rotation (L7) suggesting it moves in continual arc. She does not, however, state that it moves from east to west in this rotation, showing an incomplete description.

She also displays some incorrect ideas by stating the that the moon and sun pull and push on one another to always be in the sky at opposite times (L6–L7). She does say this is not exactly true, but her explanation in L16-L23 suggests that it is pretty close to being opposite. She also gives some idea as to why several students gave this overhead explanation and relating the motion to the rotation of the Earth in some way when she explains she learned this in second grade (L11-L12). Students did study some astronomy in the second grade in this school district. However, it did not seem that they studied it again since. As a result, she seems to be trying to remember what they learned about the phases previously. Her concept of motion is related to what they have previously studied regarding phases rather than diurnal motion.

Post-Interview

In the post interviews, students did not describe the moon as rising in the east and setting in the west in a continual motion. Several students associated the motion of the moon with another phenomena entirely. Though their explanation of that phenomenon was correct, it was not the type of motion they were asked about (Level 0). Other students were able to explain that the moon did move in the sky but of those students, most gave an incomplete description of how it moved (Level 1)

Level 0 – Changes in the Moon's Angular Distance

Several students (N=3) explained the moon moved in angular distance from the sun instead of how its diurnal motion when asked about the motion of the moon. One example of this was Kelsey:

L1. **I:** Okay. So let's think about the moon now, okay? And the last few questions are
L2. now about the moon. So does the moon appear to move across the sky at all?
L3. **S:** Um, yes, it does.
L4. **I:** Can you describe how?
L5. **S:** Um, well, a new moon, it starts off near the sun.
L6. **I:** Um-hum.
L7. **S:** And it's really small. And then each night it like gets away from the sun, and
L8. gets a little bigger. And then it moves, and back to the sun, where the new moon starts
L9. again, and then it just keeps doing that.
L10. **I:** All right. So if you were to just watch it for one night, does it appear to move
L11. across the sky?
L12. **S:** Um, it doesn't look like it.
L13. **I:** Does it change position though, if you were to check it over...okay. So how
L14. might it appear to change position?
L15. **S:** Um...well, the...the moon gets bigger. Um, and it's a little farther away from the
L16. sun when the sun sets.
L17. **I:** Does...and that happens throughout one night?
L18. **S:** Um, no.

When Kelsey is asked about how the moon moves in the sky she states the moon starts off as a new moon next to the sun and then has a progressively larger then progressively smaller angular distance from the sun (L7-L9). This was a phenomenon that was emphasized in the planetarium show as a means of helping kids think about using the moon as away to tell what time of the month it was. Her description here is correct, but it was not the type of motion that was asked about. When the question was asked differently, she first said the moon does not appear to move through the sky (L12), and then still fell back on the angular motion of the moon relative to the sun (L15-L16). Kelsey correctly described of the moon's motion relative to the sun, but does not describe diurnal motion of the moon.

Walter also showed the same interpretation of the question, but also gave a slightly more normative description of the moon's diurnal motion as well:

L1. **I:** Does the moon appear to move in the sky at all?
L2. **S:** Um, yeah [chuckles], it kind of does. Becau—and because like when you're
L3. driving your car, it looks like it's moving...
L4. **I:** So what if...
L5. **S:** ...kind of.
L6. **I:** ...you were standing still?
L7. **S:** Um, you can see the moon move a little bit...
L8. **I:** Okay.
L9. **S:** ...but...over time, yeah.
L10. **I:** How does it move over time?
L11. **S:** Well, it...when it's a new...new moon, it's really close to the sun. And then, as it
L12. grows, it...it goes farther away from the sun until they're on opposite sides of the sky.
L13. And then...and then they come back together.
L14. **I:** What about just over the course of one day?
L15. **S:** Um, kind of like...kind of like sets with the sun most...most of the time.

When Walter is first asked, he refers to the moon looking like it moves when you are driving in a car (L2-L3). This was an answer seen by many students across levels in both the pre- and post-interviews. The question was asked differently to see if he could describe the moon's diurnal motion. Instead he started talking about this angular motion relative to the sun (L11-L13). He also stated that new moon is near the sun, the moon gets farther until it is opposite the sun and then the moon and sun get close together again. This is, again, a correct description of the moon's motion relative to the sun. However, it does not get at the diurnal motion. Again the question was asked a little differently and there Walter mentions that the moon "sets with the sun" (L15). This statement suggests the moon does have a similar continual motion to the sun, but he does not elaborate to completely describe the moon's diurnal motion as an arc from east to wast.

Level 1 – Incomplete Description of the Moon's Motion

Several students (N=3) stated the moon moves in the sky, but they were unable to explain how it moves. One example is Peter, who does not offer much explanation at all:

L1. **I:** Okay. All right. Last few questions. I'm going to ask you about the moon now,

L2. okay? So does the moon appear to move in the sky at all?
L3. **S:** Um, it does but not much.
L4. **I:** Okay. So, can you describe how it...how it moves?
L5. **S:** Because it...no, I can't really describe it.

Peter states it moves, but he cannot describe how it moves at all, which he explicitly states (L5). He also states that the moon does not move much, suggesting the moon does move, but it is insignificant (L3).

Kevin offers a little more explanation but is also very quiet in his answers:

L1. **I:** Okay. Good. All right, so I'm going to ask you the last few questions. And now
L2. I'm going to talk about the moon instead, okay? So, does the moon appear to move in the
L3. sky at all?
L4. **S:** Um, yeah, like when I'm driving and I see the moon, the moon like drives with
L5. me. I don't know how it does that, but like it kind of like moves. I don't know if it's
L6. like...
L7. **I:** So what if you weren't driving and you were just sitting still. Does the moon
L8. appear to move in the sky?
L9. **S:** Not when...it might move when...I think it moves when you're sleeping but if
L10. you just...I...when I look at it, I don't see it move.

Kevin starts, similarly to Walter by first stating that the moon moves when you are driving in a car (L4-L6). Again, this was a common observation that students made. When the question was asked differently he gives a more tentative answer saying it "might move" (L9). However he qualifies that with "when you're sleeping" (L9). This suggests that he thinks it only moves in the sky at night. This could be a result of thinking it moves very slowly, as he says he doesn't see it move (L10). So he correctly states it does move, but not as an arc from east to west and he may have other non-normative ideas.

Summary of Moon's Diurnal Motion

In the pre-interviews, students frequently stated that the moon did not move and displayed different misconceptions as to where it was when we could not see it, such as stating it rotated to a dark side that we could see or it moved very far from Earth. Other students displayed an idea that could have come from their second grade unit on astronomy, stating that the moon orbited the Earth, but never quite articulating how the moon appeared to move from an Earth-bound perspective.

By the end of the unit all of the students were able to state that moon did move in the sky, rather than some students thinking the moon did not move at all. However, almost all descriptions were in some way incorrect or incomplete. Students with incomplete answers students stated it moved, but could not articulate that is moved in a continuous arc from east to west like the sun. Additionally, students were introduced to the idea of the moon having different angular separations from the sun throughout the month in the planetarium show. When asked about the moon's motion, some students gave answers that correctly described how the moon appeared to move closer and farther from the sun in the sky. However, they were never able to describe the diurnal motion of the moon. It appears several students more strongly associated the moon moving in the sky with this angular motion instead of the diurnal motion. Since this angular motion was emphasized more in the planetarium, this could potentially explain why this occurred. Furthermore, the moon's motion was not asked in the predictions students made, meaning their exposure to this idea was more limited than ideas related to the sun.

4.3.5. Moon Seen During the Day

This topic focused on whether or not it was possible to see the moon during the day at all and what determined when it was visible. Before the curriculum started, students had been keeping track of when they saw the moon on a calendar. Their teacher also took pictures when she saw the moon and showed it to the students, which included some of the moon during the day. As a result, it is not surprise that students in both pre- and post-interviews said consistently the moon was visible during the day. That said, there were some non-normative ideas that did arise and will be discussed.

Pre-Interviews

In the pre-interviews, majority of students (N=6) simply stated that the moon could be visible during the day (Level 2). This was consistent with their statements of when the moon rose compared to the sun. Namely, students were asked if the moon always rose when the sun set and most stated this was not the case. However, their answers were often curt with no indication of the conditions for when you could see the moon during the day.

Level 2 – Says the Moon Can Sometimes be Seen During the Day

One clear and example of a student at this level was Alexis:

L1. **I:** And can you ever see the moon during the day?
L2. **S:** Yes, actually you can, if you look for it.
L3. **I:** Okay. And how do you know that?
L4. **S:** Um, sometimes, like when we're riding in the car, my dad will just like..."Oh,
L5. hey, look, there's the moon."
L6. **I:** All right, cool. And does the moon always set when the sun comes up?
L7. **S:** Mmm, no...
L8. **I:** Okay.
L9. **S:** ...it actually doesn't.
L10. **I:** All right. And how do you know that?
L11. **S:** Because like sometimes around the midday it'll still be up.

Alexis states the moon can be up during the day (L2) and that it can be seen even in the middle of the day (L11). She also remains consistent in this idea when she states that the moon does not always set when the sun comes up (L7-L11). Alexis's answers are very short and to the point, but not incorrect or inconsistent. However, she does not offer any explanation for the conditions (e.g. the phases) in which the moon can be seen during the day. Similar explanations were seen with many students during the pre-interviews.

Some students answered a little differently adding in some qualifiers, as seen with Lucas:

L1. **I:** Okay. And can you ever see the moon during the day?
L2. **S:** Sometimes, if it's around probably...maybe you could see it sometimes during
L3. the day. But sometimes you can't. Because the sun might be too bright, so you can't see
L4. it. But sometimes, when it's around, when school is out, you can see it.
L5. **I:** Um-hum. Okay. And does the moon always set when the sun comes up?
L6. **S:** Um, not always. Sometimes the sun is up. And sometimes you...the moon's still
L7. up. But sometimes you can't...it's down.

Lucas states that you can sometimes see the moon during the day but there are also times that you cannot (L2-L3). His explanation for why you cannot always see the moon is that the sun could be too bright (L3). It is difficult to see the moon when it is up during the day (e.g. phases near new moon), so this is not an inaccurate statement. He also further qualifies this by saying that it can be seen when school is out (L4), suggesting it is darker and easier to seen then. Though he is qualifying when the moon can be seen during the day, he is referring more to what makes it easier to see rather than which phases allows you to see the moon during the day. His explanation also suggests correctly that it will not be seen during the day every day when he says "when it's around" (L2) and "sometimes you can't, it's down" (L7). He also shows consistency similar to Alexis by stating the moon does not always set when the sun comes up (L6).

Students generally were able to identify that the moon could be seen during the day. Occasionally they put more qualifying statements alongside the answers stating times where it might be more visible during the day. However, these qualifiers did not necessarily suggest that you could not see it at other times; it was just easier to spot at those times.

Post-Interviews

Most students still stated that the moon could be seen during the day with very similar, curt answers as in the pre-interviews. However, students also frequently said there were criteria for when you could see the moon during the day. Most commonly, this involved an incorrect criterion (Level 1). For instance some students said it depended on either the time of day or the season. On fewer occasions, students correctly identified that it depended on the phase of the moon (Level 3).

Level 1 – Incorrect Criteria for When We Can See the Moon During the Day

Several students (N=4) gave incorrect criteria for when we can the moon during the day. Peter is an example of a student who stated the two most common incorrect criteria:

L1. **I:** Okay. And can we ever see the moon during the day?
L2. **S:** Yes, you can, but at...it depends on which season and at what time you're
L3. looking.
L4. **I:** Okay. And does the moon always set when the sun comes up?
L5. **S:** No.
L6. **I:** Okay.
L7. **S:** Sometimes the moon is right in...like right on the sun, um, when it's a, um, new
L8. moon. Um, but when it's a full moon, they're like exactly opposite.

When asked if the sun can ever be seen during the day, he says it can but it depends on which season and which time you are looking at the sky (L2-L3). Some students stated it depended on just the time of day or just the season. Overall, there seemed to be an idea introduced to the students that the time or season did matter as this was not seen in the pre-interviews. Since the moon goes through a monthly cycle, the season does not affect if we can see the moon during the day. The time of day in which you can see the moon can change, but that in turn is affected by the phase. Some students did state that the time mattered to some extent in the pre-interviews, as seen with Lucas. However, the criteria seemed to move from what made it easier to spot to the moon would only be seen at certain times of day.

When asked if the moon always rises when the sun sets, Peter correctly stated that the moon and sun are only opposite during the full moon (L8). This possibly suggests there is a phase dependence on when we can see the moon during the day. However, he does not explicitly connect this back to seeing the moon during the day. This combined with his other inaccurate explanations suggests an incomplete idea of when we can see the moon during the day.

Level 3 – Says We Can See the Moon During the Day Depending on the Phase

N=2 students gave normative answers, saying that we could see the moon during the day depending on the phase of the moon. Alexis is an example of this kind of answer:

I: Okay. Can you ever see the moon during the day?
S: Yes, you can.
I: Okay. When?
S: Like if it's a crescent or...like yeah, pretty much, if it's a crescent or a quarter moon, than you can see it in the sky. It may not be very close to the sun but you can usually see it.
I: Okay. And how do you know that?
S: Um, I've seen it happening actually. And, um...yeah, I've pretty much just seen it happen.
I: All right. And does the moon always set when the sun comes up then?
S: Um, no. Because sometimes it'll stay up a little longer, and then set. And sometimes it's close to the sun, so it rises sort of with the sun. And it sets after the sun

Alexis states specifically that when the moon is a crescent or a quarter moon, you can see it in during the day (L4-L6). These are indeed the best phases to see the moon during the day. A new moon is too close to the sun to see any of the illuminated side while fuller moons are too far from the sun to be seen for long during daytime hours. She also states explicitly that when the moon is new it rises with the sun (L12). This is something that was implied by Peter and other students, but she was able to articulate more clearly.

Summary of the Moon during the day

Students could state before and after the curriculum that the moon *can* be seen during the day. This is not surprising considering the students had been tracking the lunar phases for several weeks before this curriculum began and their teacher frequently showed them pictures from her phone of the moon seen during the day. In the pre-interviews, they often gave curt answers that only stated that the moon could be seen during the day or it could best be seen in the morning or evening. Overall, they grasped the idea that the moon is not only visible during the night in the pre-interviews. However, students did show a notable shift in their explanations in the post-interviews.

In the post-interviews some students appeared to become bolder in their answers and started offering certain conditions for when the moon could be seen. Two students correctly explained that when we see the moon during the day depends on the phase, showing that at least some students were able to grasp a more sophisticated idea regarding this topic. However, most dependencies introduced were non-normative. Some, students stated incorrectly that the moon could only be seen in the morning or evening, suggesting that it is impossible to see in the middle of the day. Others stated that when we can see the moon during the day is dependent on the season. This is possibly a problem with seeing too many things in the planetarium in succession as seasons were discussed in regards to the sun and the moon portion immediately followed, suggesting students may have realized some dependencies, but misremembered or confused aspects of the show.

4.3.6. Phases of the Moon

This topic looked specifically at if students could describe that a lunar cycle included the moon waxing and waning over 1 month. The cause of the phases was not addressed in this curriculum, only that the phases occur and have a distinct pattern.

Pre-Interviews

In the pre-interviews all students showed incomplete ideas of the lunar phases. A majority of the students (N=7) stated the correct order of the phases and how the moon appeared to change shape, but did not describe the correct length for the lunar cycle (level 2).

Level 2 – Incomplete Description of the Lunar Phases

Students commonly stated that the lunar cycle only took the moon from new to full or full to new, rather than starting and ending on the same phase. Tammy displayed this idea:

L1. **I:** All right. Does the moon ever appear to change shape?

L2. **S:** Definitely. It doesn't change shape but it...the sun reflects its light on it. And
L3. it...um, it'll be a full-moon, then it'll be a little crescent missing. And then it would go all
L4. the way until there's just a little crescent.
L5. **I:** Um-hum. All right, so how often does it change shape?
L6. **S:** Every night.
L7. **I:** Okay. And is there a pattern to how it changes shape?
L8. **S:** Yes.
L9. **I:** And what's that pattern?
L10. **S:** Um, I don't know what it's called but it's...
L11. **I:** That's okay.
L12. **S:** ...like...
L13. **I:** Can you just describe it?
L14. **S:** It first goes through the full-moon. Then a little part gets like tooken off, then a
L15. little part, then a little part, then a little part, until there's almost nothing.
L16. **I:** Okay. And so how long does it take for that pattern to repeat itself?
L17. **S:** I am pretty sure it takes about a month.

Tammy twice describes the pattern of the lunar phases as a full moon that appears to get smaller until essentially a new moon (L2-L4, L14-L15). She does not complete the cycle back to a full moon by describing how it appears to get bigger after the new moon and only describes half the cycle. When asked how long it takes that pattern to repeat itself, she states about a month (L17). A full lunar cycle takes approximately one month to complete. Considering she states only half the pattern, that length of time is incorrect. Only stating half of the cycle and then stating the pattern repeated every month or so was seen with other students. It is possible these students did know the rest of the pattern and did not state it. However, what is actually described is incomplete.

Some students showed similar incomplete descriptions, where they did not know or correctly state the length of a lunar cycle but did give a more complete description of the cycle than the students discussed above. One example is Lucas:

L1. **I:** Okay. And does the moon ever appear to change shape?
L2. **S:** Yes. So like, um, when it's a new moon, it goes through the stages. And then
L3. you see the full moon. And then it goes down to a new moon, and then it just keeps on
L4. repeating.
L5. **I:** Okay. And how long does that pattern take?
L6. **S:** Mm, probably about maybe two to three weeks, I think.

Lucas describes a complete cycle of new moon back to new moon (L2-L4). He does not explicitly state what is happening in between the full and new moon, but he suggests that it waxes and wanes when he specifically states “it goes through the stages” (L2) and “it goes down to a new moon” (L3). When asked about how long that pattern takes he incorrectly says it will be two or three weeks (L6). This is close to the lunar cycle length, but still inaccurate. Again a few students showed this slightly different incomplete level of description.

A possible reason why a majority of students correctly stated the pattern and not the length cycle is because of what was emphasized in the classroom before the curriculum started. Again, the students were keeping track of the phases of the moon. So they might have started seeing the pattern in the lunar phases in what they recorded. However, they had not quite finished looking at the moon for a full cycle. Since they had not seen the moon’s full cycle, they might have lacked that knowledge. This is just a possible explanation for the prevalence of this type of description the students gave.

Post-Interviews

In the post interviews, students were evenly split (N=5 each) between incomplete descriptions similar to the pre-interviews and complete descriptions regarding the moon. Students who had an incomplete description of the lunar phases in the post-interviews either did not state the correct length of the cycle again or they did not know the order of the phases. Students with a more complete description correctly stated the phase orders and the length of the cycle.

Level 2 – Incomplete Description of the Lunar Phases

Kelsey gave a similar description as students in the pre-interview where she correctly stated the pattern of the lunar phases but not the cycle:

L1. **I:** Okay. And is there a pattern to how it changes?
L2. **S:** Um, yes, there is.
L3. **I:** Can you describe the pattern?
L4. **S:** Um, it goes from new moon...like next to the sun you can like barely see it, to
L5. getting bigger and bigger, until a full-moon. And then it gets smaller and
L6. smaller...or...yeah, and then it goes back to new moon. And then it keeps going on from
L7. there.
L8. **I:** Okay. And how long does it take to repeat that pattern?
L9. **S:** I think it was two weeks but I'm...I'm not sure.

Kelsey is able to describe that pattern of how the moon changes shape as going from new to new moon with a full moon in between (L4-L7), even explaining there is a difference in angular distance from the sun. However, when asked how long that pattern takes to repeat she says it only takes 2 weeks, half as long as it really takes. This is similar to Lucas in the pre-interviews and is an incomplete level of accuracy.

Alexis also gave an incomplete description, similar to the pre-interviews where she stated only half of the cycle, resulting in an incorrect description of the length of the cycle :

L1. **I:** And is there a pattern to how the moon changes shape?
L2. **S:** Yes.
L3. **I:** Can you describe that?
L4. **S:** It usually starts from a dark moon. And then...that's close to the sun. And then it
L5. gets farther and farther away from the sun, as it grows, as it turns. And then when it's a
L6. full moon, you can see all of it, but that's at night...
L7. **I:** Okay.
L8. **S:** ...you can see it.
L9. **I:** And how long does it take to repeat that pattern?
L10. **S:** Uh, 28 days.

Alexis explains the pattern of how the moon changes shape similar to Kelsey, starting with a new moon and then stating it grows until a full moon (L4-L6) and even stating angular separation between the moon and the sun. Again, this is correct, but she also only states half of the full cycle. When she is asked about the length of the pattern, she says 28 days (L8), which again would be correct only if she completed the pattern in her statement before. It is possible that she knew the rest of the cycle and just did not state it, but it is not explicit.

Level 3 – Complete Description of the Lunar Phases

Many students were able to articulate the full and correct pattern of the lunar cycle as well the length of that pattern to a roughly correct length. This was a level of accuracy not seen at all in the pre-interviews.

Walter shows a clear example of this in his post-interview on the lunar cycles:

> **I:** And so does the moon ever appear to change shape? You kind of started talking about that.
> **S:** Yeah, it does. It like starts out where you can't even see it. And then it grows, and you can see more of it. And then it'll have a full moon, where you can see everything. And then it'll come back and...and you can see less until it goes back new moon.
> **I:** All right, and how long does it take to repeat that pattern?
> **S:** Mm...mm, four week—four weeks.

Walter is able to clearly state the full cycle of the moon and how its shape appears to change stating the pattern of new moon to new moon with a full moon in between (L3-L6). When asked how long it takes to repeat the pattern, he is also able to clearly state that it is four weeks, which is completely accurate.

Kevin also shows a completely accurate description similar to Walter, however one of his answers is not as clear:

> **I:** Okay. And does the moon ever appear to change shape?
> **S:** Um, yes. I think it's every day at moon...the sun...I mean, the moon gets a little bigger. And then once it gets to a full moon, it gets smaller and smaller. And then it gets to a new moon. You can't see it. And then it goes back to the full...full moon.
> **I:** So how long does it take to repeat that pattern you just described?
> **S:** Um, I think it's a month to get a f—to a full moon.

Kevin also starts near the new moon in his descriptions (L2-L4), explaining the moon gets bigger, then smaller and the bigger again. When asked specifically about the length of that pattern, he says it is about a month to a full moon (L6). He could be thinking it takes a month to get from a new moon to a full moon. He could also have a more correct idea and think it is a month from full moon to full moon. It is unclear, but he is stating the normative length of the cycle of about month. This along with his correct description of the pattern suggests he may have the correct idea, but be just did not articulate it clearly.

Summary of Lunar Phases

In the pre-interviews, no student was able to correctly articulate the lunar phase cycle. Students either correctly described a full cycle of the lunar phases but incorrectly described the length of the cycle or vice versa. These types of incorrect descriptions were also seen in the post interviews, but not as frequently. There were more students that were able to correctly grasp the idea and describe the moon as starting at new moon, growing larger until full moon, growing smaller back to a new moon over 4 weeks or a month. Students did not name or even describe each and every phase the moon goes through, but were at least able to describe the general pattern.

Another interesting theme that arose was that students tended to start their discussion the cycles at new moon in the post-interviews (like Kelsey and Alexis), while students tended to start at a full moon in the pre-interviews (like Tammy). New moon is a more traditional starting point and the one shown in the planetarium, suggesting that the planetarium show had an influence on how the students thought about the lunar cycle and they were able to transfer that knowledge across the settings.

4.3.7. Summary of Strand 2 Results

A global summary of counts by topic and accuracy level is shown in Table 4-6 below. However, the qualitative analysis and descriptions of the interview data showed some more interesting results regarding student ideas and how they described ideas before and after the unit as well.

In several cases, students moved toward more normative descriptions regarding the sun and moon and were able to grasp what I will refer to as "big ideas". In particular, by the end of the unit, students were able to correctly describe aspects of the sun's apparent motion. Students were able to state and use hand motions to describe the sun's diurnal motion as a continual arc from east to west in post interviews. In the pre-interviews students either gave very inconsistent views of whether or not the sun reached zenith for their location or stated consistently that it never reached zenith while suggesting that the sun would also get very close. In the post-interviews, students more often stated that the sun could never reach zenith in their city and were better able to consistently articulate distinct and clear differences in the sun's altitude through seasons. Students moved from stating the sun rose and set in the exact or very close to same potions through the seasons to clearly stating different and distinct rise and set positions.

However, regarding the sun topics, students clearly had room for improvement even after the post-interviews and showed a possible need for more exposure to ideas. In several cases students did not correctly state details regarding their ideas. Many students incorrectly stated that the sun reached its highest point toward the North rather than South. Students were also unable to clearly state the correct rise and set positions of the sun by season, either appearing to misremember the details or associating it with incorrect ideas such as the sun always rises and sets on opposite sides of the horizon. These directional details were clearly marked and annotated in the planetarium setting, suggesting that students needed more exposure to those particular ideas afterward to help the correct ideas take hold.

One topic on the moon showed students moved from incomplete to more complete descriptions. In pre-interviews no student was able to complete describe a complete lunar cycle *and* describe the cycle's correct length, only correctly describing one or the other. However, in the post interviews students correctly stated that the lunar cycle goes from new to new moon over 28 days/four weeks/a month. Students did not clearly articulate all the phases in between, often stating that the moon "grew" between new to full and became "smaller" between full and new moon. Thus they were able to grasp the "big idea" here as well, leaving out details similar to the sun topics.

However, the other two topics related to the moon showed students introduce new alternative ideas that were not present in the pre-interviews. For instance, most students either stated the moon did not move across the sky or only described its motion from a bird's eye perspective rather than give an Earth-based view of the moon's motion in pre-interviews. In the post-interviews, some students similarly skipped describing the moon's diurnal motion instead describing the moon's apparent angular motion from the sun over the course of the month. The fact that the sun's angular position changes throughout the lunar phase cycle was shown to students in the planetarium show. However, students seemed to learn this as the expense of understanding diurnal motion. Other students simple stated that the moon did appear to move but could not articulate how. This suggests that overall students needed more exposure to this ideas across the curriculum.

The students also showed some notable shifts in their descriptions regarding whether or not we could see the moon during the day. All students both before and after the unit were able to correctly state that it was possible to see the moon during the day. However, in the pre-interviews, they simple gave curt answers with little elaboration. One student who did elaborate simple gave times of the day when it may be easier to notice it. This is compared to post-interviews where some students started to introduce dependencies of when we could see it during the day. Some correctly stated it depended on which phase it was in, but most gave incorrect ideas such as stating it depended on the season or time of day (i.e. you could not see it at noon). This suggests that students picked up some incorrect ideas along the way in the unit regarding the moon and it they may have benefitted from a more direct instruction and exposure to the correct idea.

In the post-interviews, across the questions asked, students also added in more direct as indirect references to the planetarium. As an example of a indirect reference, students started using numbers they only ever say on the meridian line projected during the show to describe the sun's altitude. They also frequently referred to what they saw in the planetarium and the visual aids used specifically in the show when reasoning through answers. This suggests that students were transferring their ideas across the settings and the planetarium visit did play a role in their ideas.

Table 4-6 Number of students at each accuracy level for each topic between pre/post interviews

	Diurnal motion of the sun		**Sun's apparent height**		**Differences between sun's path through seasons**		**Diurnal motion of the moon**		**Moon's visibility during the day**		**Lunar Phases**	
Accuracy Level	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
0	0	0	0	0	1	0	3	3	0	1	0	0
1	3	0	2	0	3	0	1	3	4	4	3	0
2	2	3	4	4	6	2	5	2	6	3	7	5
3	2	3	4	6	0	7	1	2	0	2	0	5
4	3	4	-	-	0	1	-	-	-	-	-	-

4.4. Strand 3: Engaging in Scientific Reasoning

4.4.1. Observation Lists

Students created lists of observations related to celestial motion and lunar phases. These were studied to see how well students could correctly identify proper evidence to gather in order to test predictions on celestial motion and lunar phases. The students showed a range from very vague to exceptionally explicit in how complete their observation lists or protocols were. Again, the lists were coded according to the rubric in chapter 3, Table 3-10 (pg. 90), which includes examples of what each level of completeness looked like. Figure 4-2 below shows the summative results on student completeness of observations aggregated across 4 lists each of the 11 students groups made, for a total of 44 lists.

Beyond complete lists were similar, but offered a further step to ensure validity or control of variables. Some students in other levels offered these further steps, but were also incorrect in the time and/or observations that needed to be made, and were coded at the lower level of completeness. The remaining 18% of students were coded at level 0 (incomplete) or level 1 (mostly incomplete) and offered a list of irrelevant observations or completely incorrect statements of when and what needed to be observed.

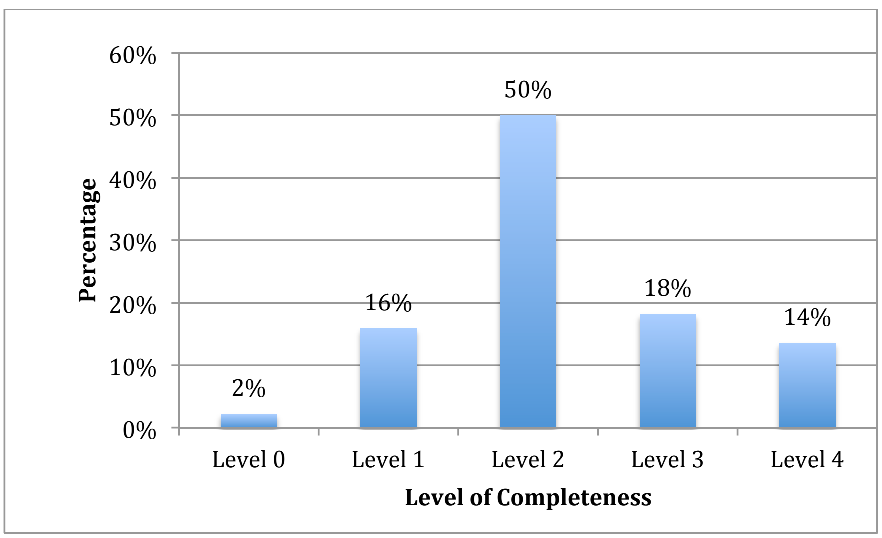


Figure 4-2 Aggregated codes for observation list completeness

Students did not entirely offer complete and explicit lists of observation. In some cases, the students that did offer a mostly complete list were only missing a simple word that would have moved them to a complete list. The fact that a majority of students offered mostly complete to complete lists of observations suggests they have some knowledge of this practice within science. However, they need better instruction and practice in designing these experiments. This is discussed further in the next chapter.

4.4.2. Justification of Answers in Interviews

I will describe 4 vignettes of student justification of answers, focusing primarily on what student justifications looked like. For all students, I will look first at their pre-interviews, followed by post-interviews with a short discussion afterward about how their justifications were different between pre- and post-interviews. In some cases, student quotes will be show in bold to illustrate a type of justification. In others, an excerpt from the interview transcript will be given with the **"I:"** representing the interview and **"S:"** representing the student being discussed. At the end of each vignette, a summary of student's justifications will be given along with a table showing the counts of justification level codes.

Kelsey

Pre-Interviews

Justifying through Memories and Observations (Levels 1 and 2) – In the pre-interviews, Kelsey occasionally relied on justifying her observations through her memories, things she had noticed or observed, or more personal experiences. For instance, when asked to justify her answer for where the sun would rise on the day of the observation (mid-February), she gave this response:

> **"Because that's where it usually is when I walk out the door."**

She simply stated an observation she had made of the sun from her personal life. Another example shows how she used observations when asked to justify her answer for the sun getting to a height "above my head" in the summer:

> **"Um, well, I do know that each point in time, like 8 o'clock, 9 o'clock, um, it's like at noon, it seems to be at the middle point, um, because it's kind of like the middle of the day. Um, and when it gets**

> **farther, and higher, down, and up, it...like it seems to be above my head. When it's earlier it seems to be off to my left. And then, when it's farther down, it seems to be at my right. So, kind of...kind of tell by the sides of me..."**

Kelsey states that the sun "seems" to be above her head. These observations offer some justification to why someone believes that something is true. This could be considered evidence that supports the idea. Kelsey starts taking things a bit further in this example though. She states where the sun seems to be at different times, implying that in the middle of the day the sun would be between these other points she observed. She does not make this connection explicit, nor does she relate that to some principle of diurnal motion. However, she does take a step beyond only evidence in her justification.

Implying connections (Level 3) – Frequently Kelsey implied connections, like the one discussed above. Some of her implications were related to a description of how the sun rotated in the sky:

> **"Um, well, it kind of moves in a...no...yeah, rotation. It comes up in the east, comes down in the west. And then it come—and then the next morning it comes up in the east, down in the west, and it just keeps like...it...you can't really tell if it's moving but it's moving like just a little bit."**

On several occasions she seems to allude to the sun "rotating" from east to west, but failed to make that connection explicit. Here is one example from when she explained the sun would set near the southwest:

I: Okay. So how do you know that'll be in the southwest?
S: Um, well, since it's...since it, um...since...it goes down in the west but it goes d—down around, and then up again. It goes down. It...like when it's coming up, it goes north.
I: Uh-huh.
S: So when it's coming down, it would go south, to come down and up again.

Kelsey is making statements like "when it's coming up, it goes north" and "when it's coming down, it would go south", mimicking language from her idea of rotation, implying a connection. However, she does not state why the sun goes to the north or south in order to complete this rotation. She is building off of ideas she stated earlier, but has trouble articulating it fully. At times she even seems to confuse herself and her answer:

I: Okay, good. And can you predict where it'll be a little later in the morning then?

S: Um, like right here. So closer to north than south.

I: Okay. And how do you know that?

S: Um, because when the sun comes up, and it comes closer this way to west...and this way's northeast – no, south, sorry – and east, um, it kind of goes from this way, up, which is...and then it hits the north mark, which...where the west starts. And it keeps going west.

She starts using the rotation of the sun from east to west as part of her explanation for why the sun will be closer to north than south. She explains what the sun is doing in the sky, but she does not connect it back to her answer of being closer to north than south. She's implying a connection between the two, but struggles saying "no…sorry". She is showing small steps towards higher levels of justification by implying a connection to the idea of rotation. However, she does not fully explain why.

Being more Explicit and Connecting Ideas Further (Levels 3) – Kelsey displays an idea that the sun moves across the sky at different rates depending on the season. Though this is an incorrect idea, she uses it as a way of justifying her answers on several occasions. Here is her most explicit use of this idea when she justified why the sun would be low toward the west in at the end of the school day in winter:

I: Okay. And can you predict where the sun will be at the end of the school day today?

S: Probably...the winter days are shorter. It gets dark at 6. So, about right...like here. It's like…yeah.

I: All right. And can you predict...actually how do you know that's where it'll be?

S: Um, well, I do know that the sun comes up in the east, and comes down in the west. From where I'm sitting, that's the west. So, um...yeah, because the west is...And the...the days are shorter in winter, so, the sun is going to go a little quicker down. And the moon is going to come up a little earlier than what it usually does.

I: Uh-huh.

S: So it's going to be a little closer down than what is usually would be.

Kelsey begins by giving a vague answer, implying because the winter days are shorter and the sun sets earlier, the sun will be low toward the west, nearing sunset (L3). She does not explicitly state this as her assumption however. She does become more explicit in her justification, when she states her assumption that sun's speed changes. She uses the idea of rotation to help justify why it would be in the west and then states that because the days are shorter in the winter the sun will have to move faster. This is why she thinks is will be lower in the sky at that time (L6-L9). Though her ideas are incorrect, she displays some higher-level justification that goes beyond simply stating facts and observations.

Using Incorrect Scientific Principles to Justify (Level 4) – Kelsey showed some slightly different justifications when discussing the moon. She often tried to bring in scientific principles and models regarding the moon's motion to explain her answers. However, she struggled to remember how to apply them. For instance, when asked to describe how the moon moves in the sky she gives this exchange:

L1. **I:** How does it move? Can you describe that?
L2. **S:** Um, well, the s—the sun...oh, that [*inaudible]*. Um, the...I know the
L3. sun has something to do with it. Um, it's like it...it's like a push and pull. Um, so when
L4. the sun goes down, ah, automatically the moon goes up. And when it starts coming down,
L5. the sun comes up. So it's like a rotation.
L6. **I:** Uh-huh.
L7. **S:** I do think the sun has something to do with it. I'm not sure what.
L8. **I:** And how do you know that?
L9. **S:** Um, I do remember some of the classes that I had a while back, uh, in like
L10. second grade, where he talked about the push and pull of the moon and sun, how they
L11. work together to like move around.

Kelsey begins by bringing up the idea of "push and pull" and the concept of gravity into her answer (L3). This is an idea related more to the tides on Earth than the apparent motion of the moon. When asked explicitly to justify her answer, she states she is remembering something from her second grade class (L10). However she is not entirely clear on how this fits together. She is trying to bring in a related scientific principle, but is unable to fully justify her answer with it, falling back on this is something she sort of remembers from several years ago. Even though she does bring in some principles, they are inappropriate for the question being asked and she is unable to truly use them for justification and seems to admit this when her statements of "I do remember" (L9).

Post-Interviews

Shorter Justifications (Level 1 and 2) – In her post-interviews, Kelsey shows a shift toward giving much shorter justifications that focused almost entirely on observations, memories, or things she had noticed. She rarely went beyond simply giving this form of evidence as her justification. For instance she offers this justification for why she knew the sun rose toward the south/southeast:

> **"Um, well, I remember looking out my window and it was like behind one of the apartment buildings. So I could like barely see it. But I could see the ray coming from behind the building."**

She only gives evidence from what she had seen in her personal life. She does go on to refer to observations made as part of the science curriculum when she refers to her justification for why the sun would be exactly west at the end of the school day:

> **"Um, well, because the sun sets in the west. And from the planetarium, it doesn't exactly go like one way or the other."**

She starts her justification by simply stating her answer again. She goes on to use the planetarium visit as her justification, rather than explaining the observations or patterns gathered from the visit. At other times, she is even less specific with regard to the source of her memories. For example, her justification for where the sun will rise in the fall is this:

> **"Um, I remember one of the…um, seasons that they kind of set in the same place. Um, I think that was spring and fall. Um, except the sunrise was different. So, um, I remember that spring was a little south. And the fall was the one that was a little *[inaudible]*"**

She simply says she remembers what she is saying and states them as fact. It could be she remembered this from the planetarium, from the project she worked on, or even from a class at some point. It is unclear where she is remembering this from, but only offers her memory as justification. These answers represent a large portion of Kelsey's justifications in the post-interviews, where she relied on what she could remember and simply stating things as fact.

Occasional Implied Connections (Level 3) – She did on occasion still offer some justification beyond her observations. For instance, she still used the idea that the sun moved at different rates as part of her justification in the post-interviews:

I: Okay. Good. And can you predict where it'll set in the summer?
S: Um, like northwest.
I: Okay. Why do you say that?
S: Um, because it takes a slower time for the sun to, um, set, since the days are longer.
I: Um-hum.
S: So, when it sets, it wouldn't exactly be in the west. Because it goes to a certain height. It wouldn't be exactly west.

She starts explaining that because the days are longer, the sun will need to move slower (L4). This change in speed will result in the sun setting somewhere other than exactly west. She does not explicitly state why this is the case however. This is one of the few times she gave any kind of justification beyond something she remembered and it resembled many of her justifications in her pre-interviews.

Summary of Kelsey

Table 4-7 Summary of justification level codes for Kelsey

	Level 0	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Total # of Justifications**
Pre-Interview Frequency **(Percentage)**	0 **(0%)**	2 **(13%)**	4 **(27%)**	3 **(20%)**	6 **(40%)**	15
Post-Interview Frequency **(Percentage)**	0 **(0%)**	3 **(20%)**	8 **(53%)**	4 **(27%)**	0 **(0%)**	15

Kelsey seems to show a decline in her justifications in the post-interviews. In her pre-interviews, she frequently relied on personal experiences but also attempted to justify her answers by introducing different and connecting facts and ideas she had, albeit very clumsily. In her post-interviews, she no longer attempted to go beyond simple observations from her personal life or from the planetarium. At other times, she simply offered memories as her justification with no indication of their source, with only a few exceptions.

Kevin

Pre-Interviews

Statements as Justification (Level 1) – During the pre-interviews, Kevin offered several different types of justifications for his answers. On a few occasions he would simply make statements that suggested his answer was his best guess. Here is a justification he offered when asked why he thought the sun would not rise exactly east in the summer:

> **"Um, because usually it's not like that direct, like right in the east, it's probably over…somewhere in the east but not right in the east."**

Here, Kevin simply states that his answer is probably true with little elaboration. He offers no kind of evidence, assumptions, or principles that might explain why that answer could be true.

Justification Through Observation (Level 2) – He also had a few instances of stating that his answer could be observed, thus giving some form of evidence. For instance, here is his response for how high the sun appears to get during the summer:

> **"Ah, higher during the summer because…it seems higher because you can see it. Like during the winter, sometimes you can't see it because it's all white. And it seems lower. But in the summer you usually can see it unless it's like raining, because it's usually blue sky."**

Kevin offers something that "you can see" as his justification initially. This is observational evidence, but it is not tied directly to any sort of principle or assumptions being made about the sun's motion or path through the sky. Afterward, he is asked to explain how he knows this and does try to offer further justification, stating a new idea that might apply. However, his answer is not clear and incomplete:

> **"Because [short pause]…well, maybe because of the year-round. And it's lower during the winter. And once it gets higher during the summer,…and it gets higher until like the end of the year or something."**

He brings in his idea of "year-round", perhaps meaning the changes in the seasons or the motion of the Earth around the sun. However, he also makes a statement of the sun being lower in the winter. He does not try to connect these statements to his observations that the sun is higher in the summer, showing an incomplete justification. However, he is trying to offer some kind of justification beyond observational evidence, but how these ideas connect together is not explicit.

Implying Connections (Level 3) – Kevin did more explicitly state ideas when talking about the sun's different positions throughout the year. Yet, he also frequently failed to connect his ideas to one another and simply implied any sort of relation between them. For instance, here is an excerpt from when he answers where the sun would be at lunchtime:

L1. **I:** Okay. All right, and can you predict where the sun will be at lunchtime today?
L2. **S:**: Ah, right in the middle of the east and the west, it'll like appear because it's the
L3. middle of a day.
L4. **I:** Okay. And why do you think that?
L5. **S:**: Because it's the middle of the day. And when it comes up in...in the morning, it
L6. sets...it's in the east. And then by night it sets in the west. So, it's the middle, so it might
L7. be in the middle. (*arcing hands)*

In this example, he starts out explaining that because it is the middle of day, the sun would be in the middle of the sky (L2-L3). He does not fully explain why that needs to be the case though, simply implying that it is important. When asked to explain further, he elaborates saying that it will be in the east in the morning and in the west in the evening, so because it is the middle of the day, it would be in the middle of those two points. He does not state any assumption on how the sun moves between those times, such as the rotation of the sun or constant movement, but he implies this kind of motion with his arm movements, resulting in a slightly more explicit idea and moving toward a more complete justification.

Explicit Connections (Level 4) – He also had a few more instances where he stated those specific assumptions about the sun's motion that helped further explain his ideas. Here is an example where he discussed how he knows the sun will set in the west in the summer:

L1. **I:** Okay. And where will the sun set? Can you predict where it will set in the
L2. summer?
L3. **S:** At the end of the day?
L4. **I:** Yeah...
L5. **S:** Ah...
L6. **I:** ...at the end of the daytime.
L7. **S:** ...down here in the west because of...because if it sets here, it would do a
L8. rotation. So, in the middle of the day it would be here. And at the end of the day it would
L9. be down here. *(arcing arms)*

In additional to arcing his arms as before, he states that the sun will "do a rotation" (L7-L8), suggesting the sun moves continually in this shape throughout the day. He used this idea of rotation to help explain where the sun will rise in the east during the fall:

> **"Um, because, ah, in like 1st grade I learned that the sun sets in the west. And if it sets is the west then it should set in the morning in the east, and then do a rotation around, and then set back down in the west."**

Kevin brings in the idea of rotation again along with the idea that the sun rises in the east and sets in the west. He helps justify the answer that the sun will rise in the east, by stating this assumption of full rotation and saying that because of and the fact it is in the west in the evening, it has to start in the east in the morning. He starts bringing in some principles of rotation of the sun to help his explanations and connecting those ideas together beyond simple observations or statement of fact and being more explicit in his verbal communication.

Post-Interviews

Observational Evidence (Level 2) – In the post interviews, Kevin had similar justifications to those in his pre-interviews. The main difference was in the frequency of certain types of justifications. For example, Kevin only gave one justification that was related to things that one could observe when asked to explain how he knew you could sometimes see the moon during the day for certain phases:

> **"Um, because, usually when I look, and I see the moon in the day, it's like a…some kind of crescent. But when it's more of a almost full moon, it…I don't really see it in the day."**

His justification is based on what he usually sees and does not go far beyond his observational evidence. This is the only time he offers a justification for the moon in his post-interviews and a justification that focuses strictly on observations.

Statements of Fact (Level 1) – He also frequently gave statements as fact though uses the facts more as evidence than just guesses like his "probably" statements. Here he offered a justification as to why the sun will set in the southwest in the summer:

> **"Because it's the summer and not the spring."**

In this example, he is implying there are differences between seasons for the rise and set positions of the sun. However, he simply states that this is because he is talking about the summer and makes no explanation as to why the difference between the seasons is at all important. There is no elaboration and does not really offer any kind of justification for his answer.

Implied Connection (Level 3) – Kevin also gave some rather incomplete justifications frequently, starting to bring in some related ideas without explicitly connecting them to his answer. Here he is asked specifically why he thinks the sun will be higher in the summer and he answers:

> **"Um [sighs]…mm, maybe because it's like out more, because in the winter it's kind of…it gets snowy and gets all like white. And in the spring it's rainy. And in the fall its kind of rainy too. So maybe it's out there more so it's higher."**

He brings in the idea of the weather to help support his idea of why the sun is higher in the summer. He starts by stating facts about the seasons and their weather patterns. He then follows up with "so maybe it's out there more, so it's higher". He's suggesting that it is warmer in the summer, so the sun is out longer in order to make it warmer, therefore it needs to have a longer path and get higher in the sky. This is at least one interpretation of his answer. However, it is not clear because he does not finish connecting these ideas together. Most of his justifications were similar to those described above where he would often imply connections by stating facts where one could presume what he meant, but never fully connecting the ideas. He would offer specific pieces of evidence or relevant information, but he did not explain why those were important and how they fit into his answer.

Being more Explicit (Level 3) – Kevin does show some instances of being a bit more explicit in his assumptions as well. For example, here he explains where the sun will be at lunchtime giving some justification as to why this is the case:

I: Okay. And can you predict where the sun will be at lunchtime today?
S: Um, since it's half the day, it'll be like right in the middle, like the highest point in the sky. So it rises, and then right in the middle of the day it'll be right here. (*arcing arms)*
I: Okay.
S: Because it's around 12. And then it'll set right there.

He is implying that because the sun moves across the sky in an arc, it would be in the middle of the sky in the middle of the day. He does not explicitly verbalize this, but he does arc his arms with his answer as part of his justification to show this is the assumption he is basing his ideas on, moving toward a more complete justification.

Summary of Kevin

Table 4-8 Summary of justification level codes for Kevin

	Level 0	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Total # of Justifications**
Pre-Interview Frequency **(Percentage)**	1 **(5%)**	2 **(11%)**	3 **(17%)**	9 **(50%)**	3 **(17%)**	18
Post-Interview Frequency **(Percentage)**	1 **(5%)**	1 **(5%)**	5 **(24%)**	14 **(66%)**	0 **(0%)**	21

Kevin had very similar types of justifications between his pre and post-interviews. He would often simply use statements of facts and attempt to connect them together in some way without fully explaining his assumptions or principles behind his answers. However, in both cases he also did show some more high-level justifications with implied or more explicit connections between ideas and assumptions he was making. On the whole, Kevin showed little change in what his justifications looked like and relied on a similar mix of types.

Alexis

Pre-Interviews

Personal Experiences (Level 2) – In her pre-interviews, Alexis gave very curt and clear answers to all of the questions. When asked to justify her answers further, she continued with short answers and relied heavily on personal experiences. For the most part, these personal experiences were observations she had made as when she answers how she knew the sun would be near zenith at lunchtime:

> **"Because, usually, when we go outside to f—like around 12 o'clock it's usually up there in the sky."**

She is basing this on her experience of where she has usually seen it around noon. Similarly, at times she gave a more personal story behind her answers:

> **"I…well, some…well, we usually go to my grandmother's in the summer. And she...we do…she does gardening, so she'll take us outside and learn….we'll just notice where it is."**

These examples are representative of most of her answers. She is saying she knows her answers because of what she has seen or noticed throughout her life. She does not offer much relation to scientific principles or assumptions about the sun's motion, only the evidence from her memories.

Hearsay as Justification (Level 1) – At times she used what she heard from others, trusting these sources have given her correct facts. Here is an example where she explained how she knew where the sun would be at the end of the school day:

> **"Um, well, I've looked an my parents have like pointed it out to me."**

Or here, where she explained how she knew the sun rises in the east during the summer:

> **"Um, my parents tell me."**

This is still a personal experience as it is something that her parents told her and she remembered. However, her evidence and justification is hearsay. It is not something she directly observed and she does not try to connect her ideas in anyway. She relies on an underlying assumed authority that her parents have on the topic.

Accepted Fact (Level 1) – At other times, Alexis just made simple statements as if they were truth and accepted fact rather than it is something she remembers or heard from anyone. For instance, when asked how she knows the sun will rise in the east in the fall she says:

> **"Because it always rises in the east."**

She simply makes this statement as if it is something that just happens. Later she gave a similar answer for how she knew that sun would set in the west, though with a tiny step toward a higher-level justification:

> **"Because, um, my parents have told me. And it rises in the east, it must set in the west."**

She does begin again by stating her parents told her. She then adds that the sun rises in the east, stating that as fact. With this she finishes by stating that because it rises in the east, it must set in the west. She's implying that there's a strong connection there that is obvious. However, she does not make any sort of explicit connection about the sun's motion that would explain why this has to be. Her justification is based on stating something more as known fact.

Explicit Assumptions (Level 3 and 4) – Almost all of Alexis's justifications for questions related to the sun were based purely on evidence or treating information as either known fact or hearsay. These are all low-level justifications that do not connect back to any specific principles or assumptions about the sun's motion. However, when she started talking about the moon, she did go beyond these more simplistic forms of justification. Here she explains where the moon goes when we cannot see it:

> **"It's really…it turns, an there's a dark side to the moon, compared to the light side. So then, when we can't see the moon, what we call a 'new moon', it's…the dark side is showing to us."**

Alexis started giving the idea that the moon turns. She connects the idea that the moon has a light and dark side, the idea that the moon rotates, and we cannot see it when the dark side is showing toward the Earth. This is an incorrect idea related to the moon, but she is able to at least state a major assumption and go beyond simply stating evidence she has gathered through hearsay or memories. However, this is only time throughout her interview she does offer this kind of justification.

Post-Interviews

Observational Evidence from Curriculum (Level 2) -- In the post-interviews, Alexis continued to frequently state only observations as her justification for her answers. However, there was a shift to justifying her answers as something she learned during the curriculum. For example, this is how she replied when asked how she knew the sun rises in the east and sets in the west:

> **"Um we've studied it. And I have also see in it happening"**

She does fall back on her own memories and observations, but she begins by stating it is something she had studied, presumably in school. Later she answered how she knew where the sun would be at lunchtime:

> **"Um, we looked at it in the planetarium and we did it on the sheets of paper. And I have also seen that it's more in that direction."**

Again, she does state that part of her justification is her own memory again, but these more personal accounts are always coupled with what she has studied as part of the curriculum. The sheets of paper to which she is referring are likely the predictions the students had to fill out as part of the curriculum. She also cites the planetarium visit as part of her justification. It is still an observation she has made, but one that is now associated with school. It is still low-level, as she is not connecting any larger ideas about the sun's motion during the curriculum.

Planetarium as Authority (Level 2) -- In the example above, Alexis used the planetarium as part of her justification. She relied heavily on the planetarium as a source of justifying her knowledge. For instance, she explained how she knew the sun would rise in the northeast in the summer:

> **"Um, we saw it in the planetarium and we've been studying it."**

Later she also explained how she knew where the sun would be at lunchtime in the summer:

> **" Um, again, in the planetarium"**

She often used the planetarium as a sole justifier or in conjunction with something she had seen in class or outside. She is treating the planetarium as enough justification rather that connecting answers back to what she learned in the planetarium overall, suggesting she sees it as having authority.

Implied Connections (Level 3) – She did show some instances of going beyond the planetarium itself as justification. For instance, she explained how she knew the sun would be at an altitude of about 30 to 40 degrees the day of the interview:

L1. **I:** Okay. And how about today, what will its highest point be, about?
L2. **S:** Um...well, it's getting closer to spring, so I would estimate about thirty or forty.
L3. **I:** Okay. And how do you know that?
L4. **S:** Um, we looked at it in the planetarium and there was a line with the numbers on

L5. it. And i—in winter it's in the 30's, the 20 and 30's. And in spring it's in the 50 and 60
L6. range.
L7. **I:** Um-hum.
L8. **S:** So, sort of in between that would be the 30 or 40 range.

Alexis starts by saying that because we were getting closer to spring, it would be 30 to 40 degrees (L2). She is implying there is a connection between the altitude and the season. When she is asked to justify further, she begins by using the planetarium and an observation she made there of the altitudes in the different seasons (L4-L8) and then uses what she remembers to state that because we are between the beginning of winter and beginning of spring, it would between those numbers. She does not make explicit how the sun's altitude changes between those seasons, but she is implying connections between her observations. The planetarium is still treated as an authority figure of sorts but she starts moving beyond just that assumed authority.

Applying Assumptions and Principles (Levels 3 and 4) – There are other instances where Alexis applied some knowledge and principles to her justifications that did not invoke the planetarium. For instance here she started implying connections between different pieces when explaining why she thinks the sun will set in the southwest, but closer to due west:

> **"Because, um, it's not winter but it's also not quite spring. It's getting away from winter. So it would probably be like around….so say this is where southwest is it would probably be around here if this is west."**

She again starts to bring in the idea the sun will set in different places between the seasons but does not explicitly make that connection or bring in evidence that the sun sets in the southwest in the winter and west in the spring to help back up what she's saying. The implication is there and she goes beyond stating it is something she has just seen. In another example, she seemed to go a little bit further in her explanation of the difference between the winter and the summer:

> **"Um, usually it moves slower in the summer, because it has a higher arc to go through. So like at noon it would be more up here, while in winter I has a littler arc to go through. So it can go faster. It doesn't really go faster, I t just seem --- appears to move faster. And you have darkness sooner. And around noon, that would be around here."**

She starts connecting some ideas together, though again not explicitly. She is stating that the sun has a higher arc to go through in the summer, which makes it seem like it goes slower. She tries to connect some idea of the sun moving at different rates but corrects herself. She seems to be implying a connection of the seasonal altitudes of the sun to arc size, which is a more normative idea. She does not fully connect the ideas, but her justification is again moving toward something that is built on more than just observations she has made.

Summary of Alexis

Table 4-9 Summary of justification level codes for Alexis

	Level 0	Level 1	Level 2	Level 3	Level 4	Total # of Justifications
Pre-Interview Frequency **(Percentage)**	0 **(0%)**	5 **(32%)**	9 **(56%)**	1 **(6%)**	1 **(6%)**	16
Post-Interview Frequency **(Percentage)**	0 **(0%)**	0 **(0%)**	13 **(65%)**	5 **(25%)**	2 **(10%)**	20

Alexis in both the pre- and post-interviews relied heavily on observations she had and her memories. These did shift from more personal experiences and hearsay in the pre-interviews to treating what she saw in class and at the planetarium as authoritative sources of information. In the post-interviews, however, she also started using more than just memories to justify her answers. She started implying connections between different pieces of information and ideas on the shape of the sun's motion. She never fully went beyond implications and her answers were far from complete, but she did show steps toward higher-level justification.

Lucas

Pre-Interviews

Statements of Common Knowledge (Level 1) – Lucas showed a wide range of justifications for his answers in the pre-interviews. In several cases, his justifications were statements of assumed common knowledge. Here are examples from when he was asked how he knew the sun would rise and set in the same position in summer as winter (which he stated as rising east and setting west earlier):

> **"Because al – the sun always rises in the east."**
>
> **"Because it always, um, sets in the west."**

Lucas is stating this is what always happens, as if this is something everybody knows. While it can be considered generally true that many people know the sun rises in the east and sets in the west, it does not use evidence or stated assumptions. He is simply restating an answer he has made. He also showed less confidence in his answers in other places in his interview. For example, here is his answer to a question about where the sun would be at the time he was interviewed where he started to justify without being prompted to do so:

> **"Mm. It's probably getting close to being straight up and down because during…around lunchtime it's probably straight up and down."**

He starts going a little beyond simply restating his answer. He is trying to explain that the sun will be near zenith at lunchtime, and since it was not quite lunchtime, it would be close to that point. However, he does not explicitly state this and his reasoning for why the sun would be at zenith at lunchtime is simply stating it probably would be, with no further explanation.

Implying Connections (Level 3) – In the next series of exchanges about where the sun would be at lunchtime that day, Lucas did start offering a reason and justification that went beyond these statements of “always” and “probably”. Here is an excerpt from his interview that shows a move toward higher-level justification:

L1. **I:** Okay. Okay. And can you predict where the sun will be at lunchtime today?
L2. **S:** Probably around...or probably just like straight up and down from...bird, like this. Like if you look straight up, you can see the sun.
L3. **I:** Okay. And how do you know that?
L4. **S:** Because it’s 12 o’clock. So it’s in be—it’s the middle of the day. So the sun is probably going to be in the middle of the sky.

Lucas starts justifying his answer and how he knows the sun will be near zenith (L2) by stating it is something one can see. This is an observation he has made in the past and because it is observable this is evidence that it will be at that location at lunchtime. It is true that the sun does not reach zenith for this location, but many people do think that is where you can see it. When asked to elaborate his justification, he starts to bring in some other ideas. He states that because it is the middle of the day, the sun should be in the middle of the sky (L4). He does not explain why this needs to be the case and does not state what his underlying assumption of the sun’s motion is in order to make his justification. As a result, it is an incomplete justification, but one that moves toward a higher level. These two examples show two different common forms of justifications he gave that went beyond “common knowledge”. Lucas did use observations and something you could see as some of his justifications throughout the interview. However, these incomplete connections of ideas were far more common.

Lucas frequently gave responses that showed he was trying to connect ideas, but he was not always confident in his answers and admitted when he was making guesses. For instance, he started giving a justification for how high the sun would be in the summer. Here is an excerpt from his interview where he discussed this:

L1. **I:** Sound good? All right, so how high does the sun appear to get during the
L2. summer?
L3. **S:** It appear—I think it gets a...when I look at it, it seems like it’s higher than when
L4. it’s in the winter.
L5. **I:** Okay.
L6. **S:** Because, um, it’s colder, so it might be a little lower. But when it’s higher, it

L7. might be going higher.
L8. **I:** Okay. And how do you know that?
L9. **S:** I...not really. I'm just guessing on that.

Lucas starts giving his justification, relating his answer to temperature. He is stating that when it is colder the sun is lower (L6-L7). This is true due to the several factors, such as length of daylight and directness of sunlight. However, when probed to explain how he knows this, he's not sure, he is just guessing. He has some idea they are connected, but he admits that he cannot fully explain why or how he knows this is the case.

Lucas shows some more explicit, though incomplete justifications elsewhere. For example, he explained how he knew the sun would be lower in the sky and on a "diagonal":

> **"Because, um, it's not lunchtime and it's no wa --- it's not, um, when you're waking up. So it's probably going to be in between there. So it might be, um, on a diagonal line or almost straight up and down."**

He is trying to explain that because of the time, the sun will between where it was between early morning and lunchtime. However he does not fully connect this idea to the motion of the sun to a continual arc or any kind of motion of the sun. He does not fully connect his ideas together and simply implying the connection exists.

Post-Interviews

Observations (Level 2) – In the post interviews, Lucas, fell back on justifications that stated his ideas as common knowledge only once. A number of his justifications were either stating observations he had made during the class unit or again showing some incomplete connections between ideas, albeit more complete than what was seen in his pre-interviews.

On two occasions he offered observations he had made during his own time and things he has just noticed. As one example he explained how he knew the sun rises in the east and sets in the west:

"Because, um, when I wake up I see the sun in the east. And when I…um, when it turns…like the sun's setting, I see it in the west."

Lucas relies on what he normally sees during his everyday life as his justification. He offers some hint that this is due to the motion of the sun when he says "when it turns", but that connection is not explicitly clear. This was a small portion of his observation-based justifications. Instead, a majority of his justifications in this regard were related to what he saw in the planetarium, similar to Alexis. Here is one example when he asked how he knows the sun will get to 75 degrees in the summer:

"Because when we were in the planetarium we did like winter, spring, and fall. And then summer was the highest out of all of them."

Shortly after, he again referred to the planetarium when explaining how he knew the sun would rise in the northeast:

"Because…um…probably because, um, in the, um, planetarium, it rose sort of like a round, um, northeast."

Lucas offered this kind of justifications that relied entirely on what he had seen in the planetarium frequently. He is stating it is an observation. However, he does not go beyond saying it was strictly something he saw there rather than explaining from an overall principles or ideas he may have learned. He was relying on his memory and the planetarium as an authoritative source or voice, similar to Alexis.

Stating Assumptions and Implying Connections (Level 3) – Lucas did not entirely rely on observations he made either outside or from the planetarium visit alone. He did go beyond this and even introduced some ideas on how the sun moved across the sky to help justify his answers. For example he offered this explanation when answering how the sun moves across the sky:

"Like, um…like, um, if we look up at it looks like a half of a…um, a cylinder. So it starts from the bottom of it, and then it moves up to the other bottom and it'll go underneath the earth. And then it'll just keep on doing that." ***(arcing arms)***

He starts describing a model of how the sun moves. He preceded this answer with describing the motion as a dome before switching to a cylinder. It is not clear if he knows the distinction between different shapes and thinks it is a cylinder, or he is confusing terms. However, he does show some general idea of how the sun appears to move across the sky, which he did not really explicitly stated in the pre-interviews. He seems to use this model as an underlying, though not frequently stated justification for his answers later in the interview. For instance, he offers a justification as part of his answer on where the sun was at the time of the interviews:

> **"Um, it's probably maybe, um, on a maybe 25-degree angle because it's closer to , um…um, to when the sun rise and…when it's going to be like lunchtime. So, um, it would normally be closer to the ground."**

Here Lucas is suggesting that because of the time of the interview (mid-morning), the sun would be closer to where it rose than where it would be at lunchtime. Here he does not explicitly state that the sun moves in any way across the sky to fully connect these ideas. This is similar to his answers in his pre-interviews. However, since he did state some sort of model or general idea of how the sun moved explicitly in the beginning of the interview, he may feel he does not need to repeat himself. He frequently gave similar types of justifications, using the time of day and different locations of the sun as a way to explaining where it would be at different times. In other cases, the connection was not as clear, but still implied, such as when he explained how he knew the sun would set in the northwest in the summer, after saying it would rise in the northeast earlier:

> **"Because it's probably…it, um…hm, because it probably sets in the same…sort of same direction but on the opposite side."**

Here, he is falling back on using a "probably statement" without clearly explaining why this is the case. We could presume that he is getting this idea from his model again, but it is not that clear that he has. Also, the use of "probably" as part of his justification rather than answer (as above), suggests a lack of confidence in his answer. Often, he started to bring in ideas like this and implying connections. This is very similar to how he justified answers in his pre-interviews. However, he at least stated an assumption earlier that fits into his implied connections, though with little explicit connections.

Summary of Lucas

Table 4-10 Summary of justification level codes for Lucas

	Level 0	Level 1	Level 2	Level 3	Level 4	Total # of Justifications
Pre-Interview Frequency **(Percentage)**	1 **(6%)**	7 **(41%)**	2 **(12%)**	6 **(35%)**	1 **(6%)**	17
Post-Interview Frequency **(Percentage)**	0 **(0%)**	3 **(14%)**	8 **(38%)**	9 **(43%)**	1 **(5%)**	21

Lucas largely showed similar types of justifications between his pre- and post-interviews. However there were some notable shifts. There was far less reliance on stating his knowledge as commonly known and he did go beyond this with only one exception. Many of his justifications offered implied connections between several different facts without explicit discussion on how those facts and pieces of evidence actually connected. However, in the post-interviews, he did make a more explicit statement on that assumption at the beginning of his interview, which did not exist in the pre-interviews, giving a more concrete foundation to his implied connections. He also relied on observations he had remembered as part of many of his justifications in both the pre- and post-interviews, though more so in the post. In the post-interview, he also relied heavily on what he had seen in the planetarium as his sole justification.

4.4.3. Summary of Strand 3

The students showed reasoning skills in both generating and using evidence between their observation protocols and interviews. In the observation lists, students were able to offer mostly complete to beyond complete lists of what and when observations needs to be made to test their predictions. However, the largest percentage still missed or stated incorrect key aspects of a useful observation protocol to test predictions. This is despite students never being directly instructed on what made an acceptable list. With additional coaching and instruction, students may be able to move closer to complete and appropriate lists.

In the interviews, the four students studied in depth offered several different types of justifications across pre- and post-interviews that ranged in sophistication. On the lower end, students would simply restate facts as if they were common knowledge (e.g. “It always rises in the east”) or hearsay (e.g. “My parents told me.”). These are not sophisticated explanations as students are simple restating facts that they know or have heard and do not connect it any overarching idea of the apparent celestial motion. Students also offered actual observations and personal experiences they have had related to the sun (e.g. “I’ve seen it there before” or “that’s what we saw at the planetarium”) as a means of justifying answers. This is a higher level of justification as it begins to offer evidence that supports their answer, not just repetition of fact. Students would also start implying or explicitly stating underlying ideas or assumptions they have made about how the sun or moon behaves as means of justifying their answer. As a major example, students would imply or explicitly state that the sun arced from east to west continually each day to explain why it would be high toward the north or south in the middle of the day. These types of justifications are more sophisticated as students are able to go beyond simply stating where the sun/moon but reason through their answers by connecting descriptions to larger ideas and assumptions.

Overall, the frequency of these types of justifications varied between students and between individual’s pre and post-interviews. One student implied assumptions more frequently in the pre-interviews while relying on less sophisticated observations and personal experiences in the post. This could possibly be explained by the emphasis on observation in the curriculum. One student showed no change in how he justified using a similar frequency of all levels of sophistication. Two students however, did show some movement away form observations and hearsay to more frequently imply or explicitly state assumptions showing that students did gain some ideas that allowed them to reason through answers. These results suggest that more explicit instruction on reasoning skills may be needed, which is discussed further in the next chapter.

It was also noted that of the four students studied, three at least once referred to the planetarium as a source of information and justification. This result is two-fold. First, this suggests that students did use and transfer knowledge from the planetarium setting into the more formal school setting, as was seen in the previous section as well. On the other hand, because many of these references to the planetarium used it as a sole source of justification, it is a less sophisticated form of justification that uses only observations made. This suggests that students are not completely extracting larger ideas for use with justification and explanations and instead treat the planetarium as an authoritative source of information when it comes to justifications. Again, this suggests that students need more explicit instruction and chances in the classroom to apply that knowledge appropriately and not rely on the planetarium's authority to justify answers.

4.5. Strand 4: Reflecting on Science

4.5.1. Likert Survey Results

Table 4-11 Likert survey response percentages for science as process

Survey Option	It is useful to listen to new ideas in science even if everyone does not agree	Scientists never finish studying astronomy	It is important to make observations in science	It is okay if scientists change their ideas about astronomy	Aggregate Percentages of Responses
5(Strongly Agree)	28%	28%	80%	24%	40%
4 (Agree)	60%	40%	20%	32%	38%
3 (Neutral)	12%	28%	0%	28%	17%
2 (Disagree)	0%	4%	0%	12%	4%
1 Disagree)	0%	0%	0%	4%	1%

This strand addresses whether or not students are able to recognize science as a process. This was an emphasized portion of the curriculum since students were asked to make predictions before and after their observations at the planetarium. Students were encouraged to refine their ideas after testing predictions and there were discussions in the classroom on whether or not it was okay to change their ideas.

Similar to strand 1, the number of students (N=25) who answered Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree were aggregated across 4 Likert survey items and percentages were calculated. Values were assigned such that Strongly agree = 5 and Strongly disagree=1. Figure 4-3 (pg. 201) shows the results in a bar graph form with colors representing the relative amount of answers on each option per Likert-survey statement with

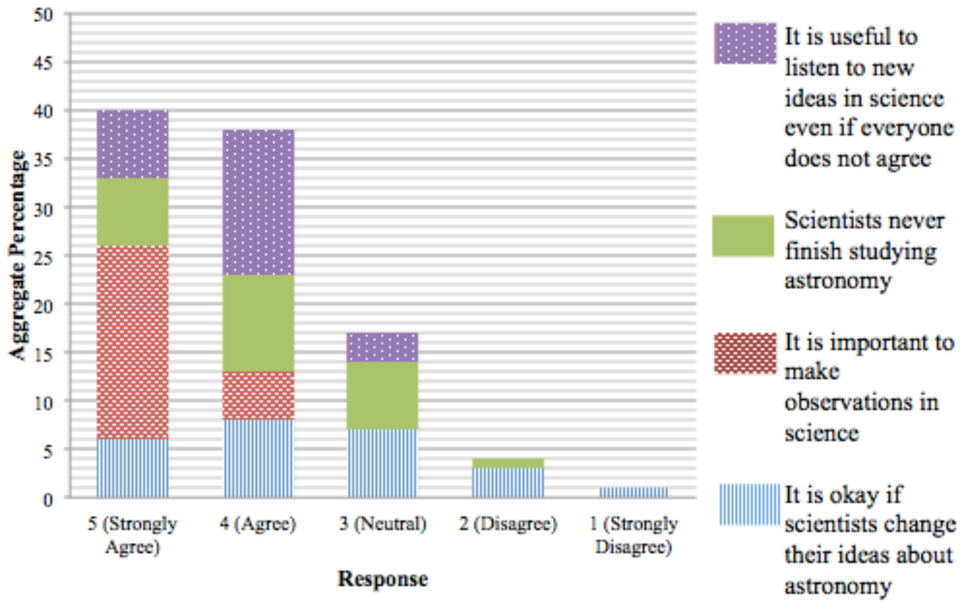


Figure 4-3 Aggregated responses to Likert survey questions on science as process

The aggregated responses show a trend toward students agreeing with the positive statements with regards to science as a process. The highest represented answer is strongly agree at 40% of responses. A majority of students either agreed or strongly agreed with a total of 78% of responses falling into those categories. Observations were emphasized in the curriculum through the predictions and the visit to the planetarium. On the item related to the importance of observing in astronomy, 80% of students strongly agreed while the remaining 20% agreed. No student was neutral, or disagreed to any degree on the importance of observations in astronomy. Furthermore, no student disagreed on the item related to listening to new ideas in astronomy, showing that students did appear to see that science is something that does need to be conducted with others. Students had the largest spread on the item related to whether or not it is okay for scientists to change their ideas. Though this was emphasized in the curriculum, this did not have as strong of an impact as the other topics.

4.6. Strand 5: Using Tools and Language of Science

4.6.1. Tools

Table 4-12 Tools used during curriculum

Tool Used	# of Observed Groups using tool
Compass Rose	6
Drafting Compass	1
Globe	1
Internet	1
Moon Chart	1
Planisphere	1
Protractor	1
Ruler	5

Tool use was not emphasized in the curriculum and use was sporadic and spontaneous as a result. However, the video did show students using some tools to help them make predictions, explain ideas, build and design their projects. Above, Table 4-12 lists the tools used and shows the number groups seen using that tool at least once. Each tool and student uses of the tool are described further below.

Compass Rose

Students were given a handout and that asked them to pick 8 static objects in the room and write down their direction on the back page. On this handout a large compass rose was printed on the front. A total of 6 student groups were noted looking at the compass rose and pointing in the direction of the objects then writing on the back, suggesting these students were using the compass as a tool to determine directions (azimuth).

Below is an exchange between two students, Alexis and Kelsey, showing how they used the compass rose as a tool to figure out the directions of objects:

A(lexis): You put these both in the wrong directions. The cabinets are west. *(points to west on the compass rose and then to the west in the classroom. Repeats this action but with the east)*

K(elsey): Oh.
A: Ok, um...[inaudible] northeast.
K: *(pointing northeast)* “So northeast? No, northwest is there”
A: No, northeast. *(turns around to face north with the compass rose and points to the northeast on the compass and then northeast in the classroom)*
K: Oh yeah.

In this exchange we can see Alexis is using the compass to help her partner. By turning it in the right direction, she makes sure that she uses the compass correctly and then uses it as a tool to show Kelsey which directions are correct. She shows this explicitly by pointing first to the compass and then to the objects in the same direction.

Drafting Compass

One group decided that while building a sundial used a drafting compass in order to make a circle for the base of their sundial. They are observed setting the compass on the paper and adjusting the radius before finally drawing the circle out.

Globe

One student, Nina, used a globe while working on her predictions for where the sun would be at different times of the day and year. Below is a transcript of her conversation with her partner, Lily, and an instructor on why she was using the globe (a ^ symbol shows voice going up, as if questioning).

N(ina): “I would say like South^ because...”
L(ily): “How do you know that Nina?”
N: “Because it’s warm in the South and it’s warm in the summer. So I would predict warm and warm go into one place. And if you are saying it’s summer and you’re saying it’s the south [inaudible] and they are both really warm. That’s how I remember it Lily. Now it’s your turn do B.”
L: “Thank you Nina. First day of fall. I think the first day of fall. September 21st, it’s going to be colder^, so it’s going to be west. Wait no, it’s gonna be a little bit east because it’s kind of colder in that area.”
S(tudent): “Lily, do you know what you’re talking about?”
L: “Yes^”
N: “We need a globe, I’m going to go see [inaudible]”
L: “While Nina does that, we’ll wait.”
E(ducator): “What are you looking at?”
N: “To see where it’s mostly warm.”

Though Nina and Lily are displaying a misconception about the sun's position, they are using the globe to help them think about their predictions within this idea for where the sun should be. The globe became a conceptual tool to help them locate the warm parts of the world presumably to check where they were relative to their location.

Internet

Students were encouraged to research questions they had or information they needed to gather. Students mentioned the Internet as a tool they used or could use at home to gather information. However, there was only one group with a confirmed usage of the internet. Since this is something many scientists would do to find journal articles or other open data they could use, the Internet was considered a tool. In one particular case, students were seen with a printed out list that audio revealed one student had printed out the night before. It included the angles a shadow would cast for a sundial for his latitude for many different times during the day. They used this data previously recorded in order to properly build their projects.

Moon Chart

Prior to starting the SMILES based curriculum in the classroom, students were keeping a moon chart. This was a calendar where they could draw the moon for each day they saw it and what time it was seen. As a class, they discussed during every science lesson if anyone saw the moon. One group of students, Walter and Lucas, remembered this record they had made and used it as a tool to help them develop further predictions about the moon during the curriculum. Below is a transcript with irrelevant parts of the conversation removed showing them using the chart as a conceptual tool:

L1. **W(alter):** When was the last time you saw the moon?
L2. **L(ucas):** Want me to get it out of my folder?

L3. ......
L4. **W:** Ah, that's perfect. That day is today. So you saw that about...just less than a week ago. That'll still help. Wait, was it actually like this or did you draw it sideways?
L5. **L:** I don't know.
L6. **W:** It seems like you have it...it's a little crescent.
L7. **L:** It will probably be like a full moon, no a new moon.
L8. **W:** So if this is right here, it seems like it's growing into a crescent. So, it should be like
L9. this. (*coloring*). Should be like that. Ok. And then. So what happens, is this...on Monday
L10. it was a new moon and then it grew so maybe it's a little smaller.
L11. **L:** Yeah because, look it, it was so small and then 1,2,3,4,5 days, so 1,2,3,4,5,6, yeah it is
L12. probably about that, just a very little smaller.

These students are using existing data they already have to find patterns they can use to extrapolate into their predictions. This is similar to scientists using existing information as a mean of creating predictions and thus targeting certain observations to make. Thus the moon chart became a conceptual tool that allowed them to make their predictions.

Planisphere

The teacher showed students a planisphere in order to discuss the concept of the sky being a dome. Two students made a 3-dimensional dome that you could move the sun to match its position on the sky. At one point in discussing their design, one of the students (Lily) brought of the planisphere over and discussed it with her partner:

> **"We're gonna make a border like this and the dome is gonna be inside of there. And this is a planisphere, so if you know the outside of a planisphere, the dome is going to be inside but the border is not going to be touching the dome, so we can just spin it."**

Lily seemed to remember the conversation her teacher had with them about the planisphere and tried using it as an example to describe her ideas to her partner. The planisphere became a conceptual tool in creating a similar but new object that one could use to tell time.

Protractor

As discussed above, Walter and Lucas used information from the Internet to help them build their sundial. In order to draw these angles they had found correctly, they used protractors to mark out the angle and then write down the associated times. They used the protractor as a precision tool in making as accurate of a sundial they could.

Ruler

Rulers were seen being used by 5 student groups in the classroom while working on their projects. 3 groups used the rulers primarily as a tool to draw straight lines rather than a measuring tool. Two groups did use the rulers for other purposes. One group used the ruler to mark out several dots that they connected to make a circle. This is similar to the use of the compass discussed above, but in a fashion that took advantage of the ruler's rigid length. Another group, Alexis and Kelsey, can be seen using the ruler and in their audio transcription you can see how they used it, along with some discussion with Lucas:

L1. **L(ucas):** You guys need the thing that makes the shadow
L2. **A(lexis)**: I know. Do you have a ruler?
L3. **L:** Do you have a ruler?
L4. **A**: Thank you. We want it at about 3 inches? 3 or 2 inches. How does 2 inches sound?
L5. **K(elsey)**: That's 2 and half.
L6. **A**: So. Gah...3 fine.

From their conversation it is clear they are using the ruler to properly measure out the size of a gnomon for their sundial. They are using it both to gauge the sizes as well as determine the best size for their design. Thus the ruler was used as a tool to actually make measurements.

4.6.2. Language

Table 4-13 Number of students that used key astronomy terms in pre/post interviews

	Zenith	Degrees	Gibbous Moon	Quarter Moon	New Moon
Pre	0	1	1	0	2
Post	4	2	0	1	7

How students used key astronomy terms in the pre- and post-interviews is discussed below. Table 4-13 above shows a summary of how many students used each term in the pre and post interviews.

Zenith

In the pre-interviews, no student used the term zenith at any point. Zenith was a term explicitly described and used with students during class discussions. The planetarium show also used the term and explicitly on several occasions including orienting students to the dome as well as pointing out that the sun never reached the zenith. As a result, students had multiple exposures to this specific term.

In the post-interviews, 4 students used zenith. Two students used it multiple times and two students only used it once. There was one major theme identified in how the students used the term. Students often used the term zenith as a referential limiting point on the sky:

> **Alexis**: It usually appears to get around the zenith point.

First Alexis explicitly states that the zenith is a point in the sky. She also uses it as a reference point in the sky to explain where the sun is. The other three students also used similar phrasing, but with a slightly added emphasis:

> **Walter:** It gets the highest it'll ever get in the whole year, so, really...just almost like really close to the Zenith but not quite.
>
> **Garrett:** Like not...um, it's almost at the zenith but not exactly at the zenith.
>
> **Tammy**: Well, this month it's probably going to get up to about, um, I would say like 50 of height. But it never goes to zenith, even in summer.

Walter, Garrett, and Tammy treat it more as an unattained limiting point. They all say things like "almost" and something such as "not quite" to explain the position of the sun in the sky. They seem to use zenith as a specific point in the sky that is an extreme limit. This limiting and referential use of the language makes sense as the students live at a latitude where the sun can get close, but not quite to zenith and this aspect of the sun's position was strongly emphasized in the planetarium show as means of countering the common misconception that the sun goes through zenith everyday. Alexis calling zenith a specific point and how Walter and Garrett further using phrasing that suggest this limiting reference point suggests that overall these three students used the term correctly and in a manner similar to that of an astronomer.

Garrett also showed one example of explicitly switching his language from his more idiosyncratic expression to zenith:

> **I(nterviewer):** Okay. And how high does the sun appear to get?
> **G(arrett):** Um, it appears to really...um, actually the highest it's ever been is in the summer. It's not even at the center, just...just barely the center, right?
> **I:** Um-hum.
> **G:** Yeah. It's not...not...doesn't even get to the zenith. Just, it's.

Garrett starts talking about the "center of the sky". He could be using center to refer to zenith or possibly some other part of the sky. He does use center in a similar limiting manner as he uses zenith using "not even" and "doesn't even" to describe both zenith and center of the sky, suggesting center is his term for zenith. However, in continuing his explanation, he uses the term zenith and never uses center again in his interview. This could be a conscious effort on his part to use the language or he was simply remembering the term. Overall, this is a shift in his language to a normative term.

Degrees

The term "degrees" was briefly mentioned by the teacher while discussing the concept of altitude and the sky as dome. In the planetarium show, the meridian was projected on the dome to help the presenter stop the sun at its highest altitude. The meridian also had degree markers on it to help the kids visualize and see a difference in the sun's highest altitude between seasons. The term "degrees" was also briefly mentioned when explaining the markers. The meridian and degree markers were meant to help students distinguish between high, medium, and low altitudes. Seven students remembered the numbers during the post interviews. However, of those 7 students, only 2 actually used the term degrees while 1 other student used it during the pre-interview.

There were two major themes found across these students in how they used the term, both of which were indicative of correct usage. First these students did refer to angles when using the term degrees in both pre- and post-interviews:

> **Tammy**: Um, at like a 60-degree angle, because it moves around the earth in a circle.
>
> **Lucas**: Um, it's probably maybe, um, on a maybe 25-degree angle because it's closer to, um...um, to when the sun rise and...when it's going to be like lunchtime. So, um, it would normally be closer to the ground.

Here, both Lucas and Tammy do not just say "degrees", but include the word angle to indicate they mean angle specifically. This shows that they both understand that they are talking about an angle in the sky and show they seem to be using the term correctly.

In addition to adding in angle, all three students appeared to use the term degrees to refer to an altitude in the sky. Several instances of the use of degrees were when students were explicitly asked about height. However, the students also used it during question that simply asked where the sun was in the sky. Here are several excerpts from their interviews, with emphasis added:

> **Tammy**: A little later in the morning? It's probably going to be at like...I'm trying to think of an angle that it'd be at, like a 60 degree angle from us, or...not that *high*.
>
> **Wendy**: Yes, because in the summer the positions are way *higher* than in the winter. Because in the winter, it only gets up to 30 through 40 degrees, probably.
>
> **Lucas**: Um, it's probably maybe, um, on a maybe 25-degree angle because it's closer to, um...um, to when the sun rise and...when it's going to be like lunchtime. So, um, it would normally be *closer to the ground.*

The students frequently would use some variation of the word "high" when also using "degrees", showing that they saw their answers as an altitude as seen with Tammy and Wendy. Lucas shows a slightly different variation when he says "closer to the ground" to indicate a difference in height in the sky. This also shows the idea of degrees as an altitude. These examples show that the students used the term correctly as an altitude, which was the primary context that they were exposed to the idea of angles and degrees on the sky.

In the examples shown above, Tammy is the one student who used degrees in the pre-interview but not in the post. She stopped using the term degrees and simply focused on the numbers:

> **Interviewer:** Okay. All right. So now I want you to think about the sun in the autumn, in the fall time, okay? And how high does the sun appear to get in the fall?
> **Tammy:** Um, in the fall it's the same thing as, um, spring; it's going to be about 50.

When asked specifically about the sun's apparent height, Tammy just gives a number of "about 50". This is approximately the altitude of the sun in degrees that was shown in the planetarium, but she does not explicitly add on the unit. With another question she adds in her own idiosyncratic unit (emphasis added):

> **Interviewer:** Okay. Good. And how high does the sun appear to get?
> **Tammy:** Well, this month it's probably going to get up to about, um, I would say like 50 ***of height***. But it never goes to zenith, even in summer.

Here, in her post-interview, Tammy switches to using the term "of height" instead of degrees. This could be because she forgot or never knew the unit was degrees. Overall, what the students seemed to focus on were the numbers associated with degrees instead of the term degrees. Tammy shows this by dropping her use of degrees and even switching to unique units. Similarly, Lucas dropped his use of degrees later in his post-interview, focusing strictly on the numbers:

> **Interviewer:** Okay. Good. And is there a difference between where the sun is during the winter and the summer?
> **Lucas:** Um...um, yes, because, um, the sun gets higher. It gets to like 75. But in the winter it maybe gets around 30. So there's a big difference in between, um, how high the sun gets.

Lucas does not continue to add on degrees for several answers, with the above being only one example. Similarly, several other students in the post interviews would use the numbers without adding on the degrees:

> **Peter**: Ah, like a 35 on the altitude *scale*.
>
> **Kevin**: Um...the altitude was like 70-something at the highest point of the day, at like 12:00. And, um...oh, yeah, like usually when it's in the middle of the sky, like...like here, it's the highest point.
>
> **Kelsey**: Um...ah, 80-ish, um, from the diagram, so, higher than any other season, some...

> **Alexis**: Um, we looked at it in the planetarium and there was a *li*ne with the numbers on it. And i—in winter it's in the 30's, the 20 and 30's. And in spring it's in the 50 and 60 range.

These other students also used numbers, but they did not add on degrees. Three of the students refer to the meridian line as well in the italicized text, showing where they got the numbers. The use of degrees was not emphasized in the planetarium show as much as the numbers. The meridian, again, was used primarily as a visual aid. It makes sense then for students to use the numbers and ignore or forget the term degrees.

The fact that student were using numbers, though, is a good step toward the direction of picking up on the term degrees and how it is used in the sky. They did not use it as a unit, but they may eventually come to realize that those numbers they use and remember that are those that are associated with the unit of degrees.

Gibbous and Quarter Moon

The students spent time before the curriculum implementation began keeping track of a moon calendar. It is unclear how much time students spent talking about the names of the phases. During the curriculum itself, the students did not explicitly talk about the names of the phases, except during the planetarium show. All lunar phases were shown to the students, including both forms of gibbous moon (waxing and waning) and quarter moons (first and third). There was one instance each of quarter moon and gibbous moon throughout the pre- and post-interviews. Both instances of use were by the same student.

The student used gibbous during her pre-interview (emphasis added):

> **Alexis**: Like it'll go from a full moon...the whole light side is showing to us. And then it'll keep turning, until a little bit of the dark side is showing to us. And now it looks like a ***gibbous moon*;** it's a little bit smaller. And then it keeps turning until it turns a crescent, a littler...littler, littler, littler.

This student does recognize that the gibbous moon is one of the several shapes the moon can be and lists as a step a long the way within the lunar cycle. In this aspect she correctly uses the phrase. However, she does not use this term again in the post-interviews. The same student used the term quarter moon during her post-interview when answering if the moon can be seen during the day (emphasis added):

> **Alexis**: Like if it's a crescent or...like yeah, pretty much, if it's a crescent or a ***quarter moon***, than you can see it in the sky. It may not be very close to the sun but you can usually see it.

She answers correctly as the quarter moon can be seen during the day. However, she is the only student to use this phrase and this is the only instance of her using it.

Though students were exposed to the term, exposure was not extensive and a very small part of the show. Furthermore, it is not common to hear the phrase quarter moon or gibbous moon in everyday language, unlike full moon or crescent moon. The lack of use of these terms is likely a failing of the curriculum, as it did not emphasize the names of the shapes the students saw, instead focusing more on the patterns of change.

New Moon

Since the new moon is a moon that cannot be seen, it is unlikely many students recorded this in their moon chart. However, 2 students did use the term new moon in the pre-interviews so it is possible they talked about in class before the curriculum started or they had heard it elsewhere. Students, were however, exposed to the new moon during the planetarium show twice. The moon portion of the show did show the students a full lunar cycle starting and ending at a new moon. Unlike gibbous and quarter moons, 7 of the 10 students interviewed used the term new moon in the post-interviews.

A theme that emerged in how the students used the term new moon in both the pre- and post-interviews was how they used it to name a specific point or aspect within the lunar cycle. Students did not simply use new moon, but they would explain some aspect of the new moon when using it. This makes sense as they were answering questions about the lunar cycle.

The students seemed to use the phrase correctly as they did explain the new moon. For example (all examples are from post interviews unless otherwise noted), students would explain that the new moon would appear near the sun in the sky:

> **Tammy**: Yes, because, um, when it's a new moon it's really close to the sun.
>
> **Kelsey**: Um, well, a new moon, it starts off near the sun.
>
> **Walter**: Well, it...when it's a new...new moon, it's really close to the sun.
>
> **Peter**: Sometimes the moon is right in...like right on the sun, um, when it's a, um, new moon.

The students would explain that the new moon is when the moon was "close", "near" or "right on top of" the sun. They did not need to use the statement of new moon to explain that phenomena, but they made that connection explicit.

Students also frequently described the new moon as the phase we could not see:

> **Kelsey**: Um, it goes from new moon...like next to the sun you can like barely see it, to getting bigger and bigger, until a full-moon.
>
> **Lucas**: So, like a new moon, you can't even see any.
>
> **Kevin**: ...And then it gets to a new moon. You can't see it....(*ellipses added)*

Similarly, the students would explain a phenomena, a phase where you cannot see the moon, and make sure to add in the name as well. There is no need to state the phrase "new moon", but they would add it in while explaining this phase of the moon.

The students would also describe it as the phase that is a counterpoint to the full moon:

> **Lucas**: So, like a new moon, you can't even see any. And then it comes into a little sliver, and then it just keeps on moving up into a half of it. And then it'll keep on moving. Then the other half would...then there will be some part of the moon on the other half. And then, it will turn into a full moon. And then it'll just do that phase, opposite, down.
>
> **Kelsey**: Um, it goes from new moon...like next to the sun you can like barely see it, to getting bigger and bigger, until a full-moon. And then it gets smaller and smaller...or...yeah, and then it goes back to new moon. And then it keeps going on from there.
>
> **Kevin**: Um, yes. I think it's every day at moon...the sun...I mean, the moon gets a little bigger. And then once it gets to a full moon, it gets smaller and smaller. And then it gets to a new moon. You can't see it. And then it goes back to the full...full moon.

They again described a point where the moon is either opposite the full moon or a point a special point that is not the full moon, with the implication of opposing points.

Overall, the students consistently explained aspects of the new moon rather than simply stating new moon. They did not do give similar explanations with the full moon; they simply slid it into the conversation, with the meaning implied. This could be the result of new moon not being a common phrase used in everyday language, where phrasing such as full moon come up often (e.g. wolves howl at the full moon, beware of the full moon). Because new moon is less common they may have felt a need to explain it either for themselves or for their audience. Whatever the reasons, the explanations are correct characterizations of the new moon showing that they did use the term correctly as the phase where you cannot see the moon, that is apparently close to the sun and the opposite point of the full moon in the lunar cycle.

Students also frequently used the term new moon as a "special" or starting point within the lunar cycle:

> **Lucas (PRE):** Yes. So like, um, when it's a new moon, it goes through the stages. And then you see the full moon. And then it goes down to a new moon, and then it just keeps on repeating.
>
> **Kelsey**: Um, well, a new moon, it starts off near the sun. And it's really small. And then each night it like gets away from the sun, and gets a little bigger. And then it moves, and back to the sun, where the ***new moon starts again,*** and then it just keeps doing that.
>
> **Garrett:** It's gets farther away from the sun. And then, um***, like every month they have like a new moon, right****?*
>
> **Walter**: Yeah, it does. It like starts out where you can't even see it. And then it grows, and you can see more of it. And then it'll have a full moon, where you can see everything. And then it'll come back and...and you can see less until it ***goes back new moon.***
>
> **Peter**: Ah, because that happens. Like a full moon happens, and then takes two weeks. And then the new moon will happen. And then it takes four weeks for another one to appear again. So, it takes four weeks for a full moon to get to another full moon. ***But in between that two weeks, there'll be a new moon.***

The students all treat the new moon as a special point either between full moons or other phases happen between a new moon and full moon. However, the students do not mention these other phases. This emphasis from the students could be a result of it being treated similarly in the planetarium show where new moon and the full moon were both treated as special points.

On the whole student answers were similar and consistent. Lucas and Alexis were students who used new moon in both pre- and post-interviews. Lucas used the term similarly in both pre and post, making sure to explain what he meant by new moon in both cases. Alexis on the other hand did not use the term at all in her post interviews. Below shows how she used it before in the pre interview and how she later switched to a more idiosyncratic term for new moon in the post:

> **Alexis (PRE):** It's really...it turns, and there's a dark side to the moon, compared to the light side. So then, when we can't see the moon, what we call a new moon (*new moon in air quotes)*, it's...the dark side...
>
> **Alexis (POST):** It usually starts from a dark moon. And then...that's close to the sun. And then it gets farther and farther away from the sun, as it grows, as it turns. And then when it's a full moon, you can see all of it, but that's at night...

She refers to new moon as a dark moon in the post interviews. It's unclear why she made this shift from the correct term to a unique term. It could be she was fairly new to the term and simply forgot or she wanted to make sure she explained the shape of the moon. The emphasis of new moon being a moon we cannot see could explain the shift, but she does give a similar explanation in both pre- and post-interviews and still manages to use the term correctly first. Alexis is the only student to show this shift toward idiosyncratic language and it is possible she simply chose not to use it for some reason in the post-interviews.

Though there was one student who dropped the usage of new moon, it seems to be a phrase that the students did learn and used in the conversation. They consistently offered explanations, but learned the correct term as shown by those explanations. Perhaps the planetarium show's emphasis on new moon as a special point and important point in the lunar cycle contributed to this as the student language of new moon did mirror this. Gibbous and Quarter moon were not emphasized in a similar manner. Perhaps, if they were, students would have also used those phrases on a similar level of explanation. This is likely a fault primarily with the curriculum for not fully emphasizing those terms.

4.6.3. Summary of Strand 5 Results

Students used a variety of tools in class to help them talk about their predictions and build their projects. These included tools that were used primarily for measuring and building their projects (compass rose printed onto paper, a drafting compass, rulers, protractor), or reference for information in building their projects or making predictions (Internet, globe, moon observations, planisphere). Most tools, with the exception of the ruler and compass rose, were only used by a single group in a way that was idiosyncratic to them as there were no specific tools that were emphasized. This was with no prompting in the instruction for them to use any of these tools, showing that students did have a sense of how to appropriately use tools related to science. Additionally, since students did this without prompting, it further suggests that autonomy in the classroom was at least not inappropriate and students could be allowed this.

Students also started the terms zenith and new moon and in the post-interviews in astronomy appropriate ways. Students used zenith as a limiting point in the sky that the sun could never reach. New moon was used as the starting point in the lunar cycle and explicitly described by students as the phase that could not be seen or was right next to the sun. On a lesser scale, two students did start using degrees in the post interview as an angular altitude of the sun. However, several other students did use numbers similarly, implying degrees just not explicitly stating the unit. Almost no students used the terms quarter moon or gibbous moon in the pre- or post-interviews. A possible reason or why certain terms were more widely adopted than others is emphasis and exposure. New moon and zenith terms were emphasized more so than other terms in the planetarium show and the classroom. The term degrees was only used briefly in the planetarium as a quick introduction to the meridian line and why there were numbers, which students grasped onto more so than the unit itself. Additionally, the terms gibbous and quarter moon were only briefly mentioned while observing how the moon changed in the planetarium show and were not explicitly discussed before or after the visit. This suggests that students will more likely adopt the vocabulary terms that students are exposed to more.

4.7. Strand 6: Identifying with the Scientific Enterprise

4.7.1. Likert Survey Results

This strand addresses whether or not students see themselves as someone who can do and understand science. The responses for strongly agree, agree, neutral, disagree, and strongly disagree were aggregated across all 4 Likert-style items that 25 students were given on the identification with the scientific enterprise. Values were assigned to the responses that students gave. Unlike the other Likert-scale items, this strand had two positive statements where

Table 4-14 Likert survey response percentages for identification as scientist

Survey Option	Only astronomers can understand astronomy (Reversed)	Only astronomers use astronomical information (Reversed)	I might like to be an astronomer when I grow up	I can understand astronomy	Aggregate Percentages of Responses
5 (Strongly Agree)	60%	28%	8%	36%	33%
4 (Agree)	20%	44%	12%	36%	28%
3(Neutral)	16%	24%	48%	20%	27%
2 (Disagree)	0%	0%	20%	8%	7%
1 (Strongly Disagree)	4%	4%	12%	0%	5%

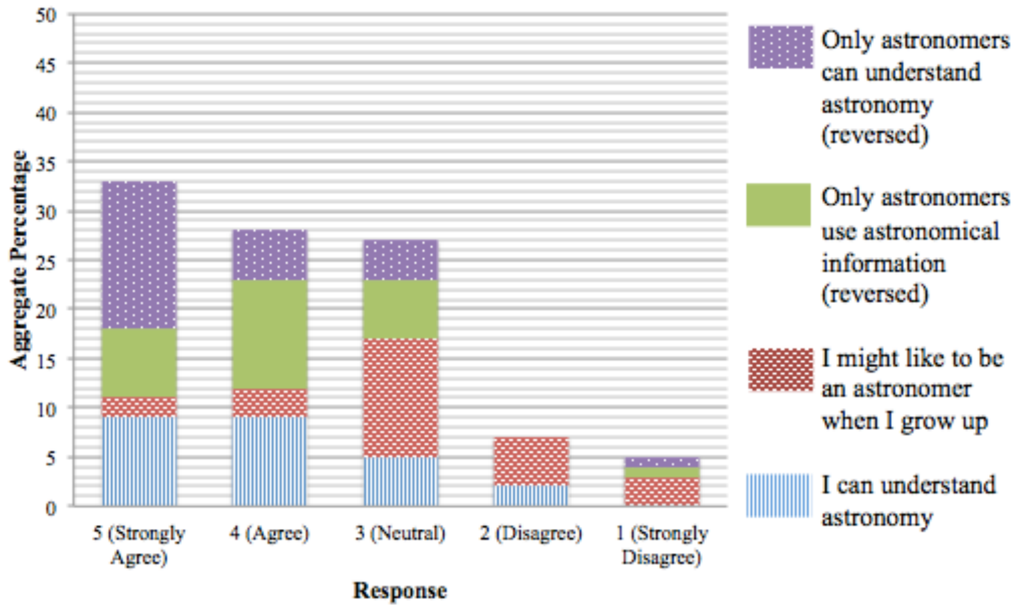


Figure 4-4 Aggregate responses for Likert survey items on identification with science

agreement suggested that students identified with the scientific enterprise and two negative statements where disagreement suggested students identified with the scientific enterprise. To facilitate comparison, positive statements were assigned values such that Strongly Agree = 5 and Strongly Disagree =1, while negative statements were reversed. The overall percentages were calculated and given in Table 4-14 (pg. 217). Additionally, the results are shown in bar graph form, showing the relative number of responses per question.

The trend seen here is toward agree or strongly agree where the highest represented response is strongly agree with 33% of the responses. A majority of responses (61%) either fell under strongly agree or agree. However, neutral is also highly represented at 27%. The majority in this set of Likert-scales items is not as strong as others, with an almost equal number of responses falling under agree and neutral. There are very few statements, so there can be bias from a single question emphasizing that difference. For instance, the statement "I would like to be an astronomer" may be offering significant bias. These students are young and may not know what they want to do for a career. This could have resulted in the large bump from that question in the neutral slot. However, the fact that students are neutral and not outright denying it as a career choice is positive. Additionally, disagree and strongly disagree options were more represented than other Likert items, but were still relatively low with only 12% of total responses.

Only one student strongly agreed with statements relating specifically to astronomers being the only ones who can use and understand astronomy. Additionally, a majority of students agreed that they could understand astronomy. This suggests that students did feel some self-competence. This also suggests that students do see a use for astronomy in their everyday life. A discussion on how astronomy was relevant in student lives was discussed as part of the curriculum and it is possible it had a positive effect on students' views. However, it is also possible they held this view prior to the curriculum.

Chapter 5

DISCUSSION

5.1. Overview

This chapter discusses the results seen in the previous chapter, their implications for using the SMILES framework with planetarium environments, and address the second research question:

- **How do the examples of the 6 strands of informal learning suggest revisions to the SMILES frameworks in order to be more usable with planetaria?**

The discussion will first be organized by strand of informal learning and include implications from the results for how well the SMILES framework applies to school-planetarium contexts. The end of the chapter will discuss revised guidelines for planetaria in each principle of SMILES based on the results. Only guidelines affected by the results are discussed in detail. I will tentatively refer to the revised set of guidelines as the School-Planetarium Integrated Curriculum Approach (SPICA) in order to distinguish it from SMILES. Additionally, some suggested guideline changes are potentially applicable across multiple types of informal environments, including museums. As a result, suggestions for specific implementation in planetarium and similar settings will be discussed.

5.2. Strand 1: Sparking Interest and Excitement

5.2.1. Discussion of Results

The results from Strand 1 showed different examples of student interest and excitement toward astronomy. This was first seen in the self-reported data from the Likert-surveys, which showed a strong trend toward students agreeing and strongly agreeing with 82% of the responses falling under those two points in items related to interest and excitement. Two of the items focused on interest and excitement in astronomy as a general topic rather than focusing on specific aspects of the curriculum. It is possible that students may have had some broader interest in astronomy before the unit, which could be reflected in the results. However, it does show an example of the interest and excitement strand being at least being present with these students during the implementation of this curriculum.

Two statements related specifically to the planetarium visit were included in the survey and can give an indication of its distinct role in students' interest and excitement. These items showed the strongest positive results with 76% of students strongly agreeing that the planetarium visit was interesting and enjoyable and over 90% of students agreeing or strongly agreeing. Since these items were directly referring to the visit, the planetarium likely played a role in the positive results. Planetaria have often been shown to result in affective gains for students and it is a major goal of planetarium operators in their shows (Lelliot, 2007; Ridky, 1974; Small & Plummer, 2010; Sunal, 1973). It is not unexpected or unreasonable to suggest the planetarium did contribute to the students' interest and excitement and shows a positive reason to maintain these sorts of visits.

The mini-case studies of groups working on their projects also showed students engaged with the curriculum in ways that could be indicative of interest in the topic including their deep level of thought, prolonged engagement with tasks, showing curiosity, asking meaningful questions, persevering through problems, taking initiative, and thoroughly planning out their projects (Hidi, 2000; Renniger, 2000; Schunk et al., 1996). These types of engagement were seen more frequently with 3 of the 4 case studies conducted. This shows an example of interest and excitement in the classroom while working on a part of the curriculum, suggesting the curriculum itself did help provide conditions for sparking interest and excitement. However, there were also some weaknesses found in the case studies regarding this particular example.

There were some indicators that some students' engagement was motivated by factors outside of interest. Interest can be tied to intrinsic motivation while extrinsic motivation can suggest lack of interest (Hidi, 2000; Sansone & Harackiewicz, 2000). Intrinsic motivation is seen with students who take on a mastery goal orientation in their work, meaning students are more likely to want to learn for the sake of learning and to deeply engage and persevere through problems (Pintrich et al., 1993; Renniger, 2000; Sansone & Smith, 2000; Schunk et al., 1996). This is opposed to performance goal orientations where students have a goal of doing well relative to others, gaining good grades, and besting other students (Pintrich et al., 1993; Schunk et al., 1996). There were some behaviors indicative to performance goal orientations such as Olivia's focus on ease of her project for deciding what to do or Lucas's announcing to the class that his and Walter's project worked and telling others how to do their projects. Olivia and Lucas's motivation for doing the project may be linked to getting good grades or showing off intelligence and not an intrinsic interest in the topic. However, these were concurrent with other behaviors consistent with mastery goal orientation such as thoughtful discussions, detailed planning, and seeking help when needed (Pintrich et al., 1993; Schunk et al., 1996). Furthermore, some researchers have suggested that performance goal and mastery goals are not necessarily opposite ends of a spectrum, but can be concurrent and can both indicate interest depending on the context (Sansone & Smith, 2000; Schunk et al., 1996). This means interest is not necessarily ruled out by these behaviors only made ambiguous.

There was one mini-case study where the students did show frequent forms of engagement inconsistent with interest. Nina and Lily did not take their project seriously, did not listen to advice, were focused more on the surface-level decorative aspects of their project, and were off-task more frequently than other students. Their lack of meaningful engagement could be tied to their challenges in applying the underlying astronomy content of the unit. They both displayed difficulties in applying their knowledge and explicitly stated their difficulties in understanding the topic, suggesting the content was too challenging for them. When activities are too challenging for students or their self-perceived competence in a topic is low, they may lose motivation in the task or the topic (Bergin, 1999; Renniger, 2000; Schunk et al., 1996). This suggests the curriculum needed to address Nina and Lily's ability level a bit more directly. With this particular case, it is likely they needed some extra support through pre- or post-activities, suggesting this was an issue with the curriculum needing to address students of different levels.

The social dynamics between Lily and Nina could have also played a role in their lack of meaningful engagement. It is generally accepted that people learn socially, particularly in informal settings (Falk & Dierking, 2000; Vygotsky, 1978; Witcomb, 2006). For this reason, research in integrating learning across settings suggests giving students opportunities to work in groups (DeWitt & Osbourne, 2007; Griffin, 1998). However, social interactions are complicated and peers can influence students' motivation and interest. Students can lose motivation and interest to work in order to socialize with friends or maintain a certain reputation (Bergin, 1999; Schunk et al., 1996). Students can also affect each other's self-perceptions of competence, which can also affect motivation (Schunk et al., 1996). Nina dominated conversations, disregarded Lily's ideas, and pulled her into off-task behavior on several occasions, resulting in a lack of engagement with the project. The teacher chose the groups for the students as this was what she was most comfortable with and she used her best judgment for students that may have worked best together. In the other cases students were able to avoid conflict, or eventually work through their disagreements. Thus, the teacher's judgment appeared appropriate for a majority of groups studied, but may have needed to be adjusted in the case of Lily and Nina.

5.2.2. Implications for the SMILES Framework

The second SMILES principle addresses guidelines related to providing conditions for self-directed learning. One important guideline within this principle is to give students choice and control in their learning episodes in order to foster curiosity and for students to find information in their own areas of inquiry. Within SMILES, these guidelines refer primarily to students working and learning in the museum. Due to the constrained nature of the planetarium, choice and curiosity were fostered in the classroom through the projects students did. Though there was one group whose engagement with these projects suggested lack of interest, the other 3 groups showed deeper engagement including thoughtful discussions, detailed planning, and perseverance through problems. A change in the curriculum to scaffold learning further and extend the curriculum with more pre- and post-activities could support the remaining group, who appeared to struggle in understanding the content. Otherwise, moving these aspects of choice and control into the classroom was a positive initial change to the framework and one that can be made more explicit in SMILES regarding the guidelines for planetaria.

Another guideline of the second SMILES principle is that students should be allowed to form autonomous groups, each accompanied by an adult who can provide necessary support.

Again, this is referring to the students' experience in the museum and includes allowing students to choose their partners or group mates. Autonomous groups are not possible within the context of the planetarium show as it something the whole class experiences together. Autonomous groups, in this case were fostered in the classroom by allowing them complete control over their project. However, students were not allowed to pick their partner. Students prefer to work with friends but sometimes this is distracting and the teacher may need to split students up making the teacher more comfortable with choosing groups to maintain a productive classroom environment (Bergin, 1999; Griffin, 1998). Research regarding motivation suggests that students should be grouped according the teacher's judgment into heterogeneous ability groups where everyone is given a specific responsibility. This can help students feel more responsible for their learning and improve self-perceptions which can in turn positively affect motivation and interest (Schunk et al., 1996). The autonomous groups guideline in SMILES may need to be adjusted to address these more complicated in-class social-dynamics and to mitigate the more negative consequences of grouping certain students together, as was seen with Lily and Nina.

5.3. Strand 2: Understanding Scientific Content and Knowledge

5.3.1. Discussion of Results

This strand looks specifically at students' explanations and descriptions of apparent celestial motion and was addressed through student interviews on the apparent motion of the sun and moon. The results regarding the motion of the sun showed most students interviewed were able to grasp the "big picture", meaning after the curriculum they were able to state that the sun moves in a continuous path from east to west, it never reaches zenith (true for North America), and there are seasonal changes to the sun's path including differences in the rise and set positions and the sun's highest altitude. The curriculum and planetarium visit were successful to some extent and showed an example of students correctly describing apparent motion of the sun.

Though students did correctly describe global aspects of the sun's motion, they also displayed some notable weaknesses. Students incorrectly stated many key details regarding the sun's motion. Few students were able to correctly describe the sun's daily path as an arc that is tilted toward the south, instead describing it as an arc was titled toward the north. Most students were also unable to correctly identify the apparent rise and set positions of the sun based on seasons. A full understanding of seasons does require knowledge of seasonal rise and set positions and the different sized paths the sun takes.

Some aspects could have possibly been mediated by an extended curriculum. Students need multiple exposures to ideas and it can take some time for them to properly adjust existing ideas toward normative ones (Minstrell, 1989; Posner et al., 1982). Some answers and details students stated incorrectly involved ideas that the sun always had to rise and set on the exact opposite side of the sky, which only happens twice a year. These misconceptions could have existed prior to the curriculum and students were not sufficiently exposed to normative ideas to adjust their mental models. Model-based learning, where students iteratively develop and critique models, can be useful in helping students learn topics and be able to understand concepts at a deeper level (Bransford et al., 2000; Lehrer & Schauble, 2006). Thus, students could have benefitted from discussion of models or causes of what they saw to act as a basis for how they considered the motion of the sun, again suggesting the need for an extended curriculum. Additionally, having students build models of natural phenomena is an expected part of the Next Generation Science Standards that teachers will use to guide their instruction in coming years

(National Research Council, 2012), meaning curricula that allows students to create and/or use models should be encouraged in classrooms anyway.

The students were also asked about the moon's apparent motion and phases. The results regarding the moon were not as positive as the sun, though they did learn some aspects of the lunar phases. Most students were able to correctly identify the correct length of a lunar cycle and the pattern the moon's shape after the unit. Many students were also able to correctly state that the moon can be visible during the day after the curriculum and all were able to state the moon did move in the sky in some way after the curriculum.

Despite some positive improvements regarding description of the moon's apparent motion and phases, students did show far more difficulty in describing aspects of the moon's apparent motion than with the sun. Many students did not correctly identify the moon's motions from east to west in a continual arc when asked about the diurnal motion of the moon. Several instead stated the moon moved in angular distance from the sun over a 1-month cycle. This is correct and their descriptions of this type of motion were accurate. However, it was not the type of motion they were asked about, nor did the student statements describe diurnal motion of the moon when the question was asked differently. They appeared to learn about the angular position changes at the expense of proper descriptions of diurnal motion.

The angular separation between the moon and the sun was emphasized in the planetarium show with the intent of showing students that the moon can be up during the day and the separation can act as a way of telling time of month. The diurnal motion was also shown to students at several points in the show to also emphasize that it moves like the sun throughout the day. This emphasis and presentation likely caused students to confuse the types of motion. As a result, aspects of the planetarium show should be modified to help address and reduce this confusion. Furthermore, the diurnal motion of the moon was not emphasized in the rest of the curriculum. Had the diurnal motion been emphasized more in predictions or post-activities, students would have had more exposure to this idea, possibly helping them to give a more normative description.

Other issues regarded whether or not we could see the moon during the day. Many students stated that we could see the moon during the day in both the pre- and post-interviews. In the pre-interviews, students rarely elaborated their answers, simply stating that it was possible. In the post-interviews, many students offered a contingency for when we could see the moon during the day, many of which were inaccurate. Common dependencies that students offered were the seasons or the time of day. The moon can be seen during the day in any season and the time of day does not matter beyond it being somewhat more difficult to spot, though still visible depending on the phase.

Some of these misconceptions could also be attributed to the planetarium show. As discussed in Chapter 2, learning is situated in the context it is learned (Brown et al., 1989; Driver, 1985; Lave & Wenger, 1991). Students were taught about celestial motion and aspects to of the lunar phases in the single planetarium show. There was no gap between the students learning each topic. As a result, the context was exactly the same and the immediate juxtaposition of these topics may have confused students. The curriculum in general did not emphasize the dependencies of when we could see the moon during the day. It was not intended to address this, though many students did apparently make these unexpected and unintended associations. As a result, the curriculum and planetarium show could be changed to make the differences and change in topic more explicit for students.

5.3.2. Implications for the SMILES Framework

Some of the weaknesses seen within the content strand could be related to the curriculum itself and its emphasis on certain topics and not others. However, the SMILES guidelines were used to create this curriculum and so there is potential to address at least some of its shortcomings in the framework. The structure of content and the curriculum is particularly addressed in the first SMILES principle of integrating school and museum learning.

One important guideline in the first principle is to "clarify with the students the purpose and use " of museum learning particularly indicating how they will use the information at school after the visit. This guideline was addressed in the curriculum through class discussion on using the planetarium as a way of testing their predictions and how they would use the information back in the classroom to design and build their projects. However, they did not reference or explicitly revisit the information from the planetarium outside of a post-activity that required them to just remember what they saw. As stated earlier, students cannot be expected to fully learn something in a single visit (Falk et al., 2006; Minstrell, 1989; Posner et al., 1982) and learning is tied to the context in which is learned (Brown et al., 1989; Lave & Wenger, 1991). Telling students how they will use the information is an important aspect of integration. However, they may need some explicit means of addressing the content in both settings in order to expose them to the same ideas multiple times across different situations and contexts.

Worksheets have been studied extensively in museum settings as a means of helping students gather information while on a field trip. A lot of research has shown that worksheets are not terribly useful as teachers do not refer back to them, they ask generic and cognitively low-level questions, students find them boring, and they can restrict the level of choice and control students in their learning (Griffin, 1994; Kisiel, 2003b; Price & Hein, 1991). However, if worksheets are used in a way that promotes control in the museum and having students ask questions they can use *back in the classroom*, they can be useful (Griffin, 1998). This suggests that allowing students an appropriate way to collect information can support learning across the settings.

There has also been successful work with helping students integrate learning using applications (“apps”) on mobile technology (Kuhn, 2012; Quintana, 2012; Songer, 2006; Vavoula, Meek, Sharples, & Rudman, 2006). Using mobile devices offers many affordances such as maintaining choice and control for students while streamlining annotation of data for use later (Cahill, et al., 2011; Cahill, et al., 2011; Cahill et al., 2012; Kuhn et al., 2012; Lo et al., 2012). These features allow students to collect data while on a field trip, remember why they thought data was important, and have explicit access to that collected information back in the classroom.

Based on this research, students may benefit from an opportunity as soon as possible after the show, preferably while still on location, to record information that they saw during the planetarium show. What students record should be revisited while in the classroom as a distinct part of post-visit activities and used as reference during post-activities to extend exposure as well. For instance, in this curriculum, students could have re-done their predictions on the same kind of handout immediately after the show and explicitly referred to them to work on the ranking activities and projects. This type of post-activity as soon after the show as possible should also be reflected in the SMILES guidelines.

However, the exact structure of how students collect information may need to better reflect the planetarium setting. The success of mobile devices and choice and control-based worksheets is tied to them matching the affordances of the choice-based environment of a museum. Since planetarium settings do not offer the same level of choice as museum field trips, are in a purposefully dark room, and are more structured than a museum visit it may be difficult to allow data collection with light-emitting mobile devices or choice-based worksheets. Because the show is structured and addresses specific topics, the means of data collection sheets should explicitly address what was seen in the show rather than be open ended to make sure students are not missing key information and details they may need later, such as the exact rise and set positions in this show used in this curriculum. Ultimately this means we need to match the structured nature of data collection with the structured nature of the show. Thus the guidelines should point more specifically to structured data collection for planetaria.

In addition to a need for additional exposure, some of the issues with student descriptions regarding the moon in particular could be attributed to the structure of the planetarium show and the fact that students were shown a diverse set of content in the same context. Additionally, the show was designed to address the guideline “Anticipate variations in students' concentration and depth of examination of exhibits over the period of the visit” in the third SMILES principle related to facilitating appropriate learning strategies. Physical and mental fatigue while at museums has been suggested in museums settings (Bitgood, 2009b; Davey, 2005). To address possible mental fatigue in the planetarium, the end of the show was on a topic unrelated to celestial motion and addressed constellations that could be seen that night very informally. However, many students seemed to mix up details from the first half of the show related to the sun and the second half related to the moon, such as stating the moon's motion depended on seasons. This along with the fact that student answers were less accurate regarding the moon could possibly be attributed to mental fatigue along with the context compressing too much information in a small amount of time. Thus, it may be desirable for students to focus on only one major theme (e.g. sun's apparent motion OR moon's apparent motion) during a show that is limited in time to help focus the students' attention, particularly shows that are given by presenters of varying skill levels. Some planetarium operators may be more skilled and capable of coherently discussing multiple topics. If multiple topics are addressed, the shift in topic should somehow be clearly delineated so students note it as a new context. Structural aspects of shows, such as this, need to be addressed explicitly in the guidelines for show-based informal environments such as planetaria.

5.4. Strand 3: Engaging in Scientific Reasoning

5.4.1. Discussion of Results

The reasoning strand looks at how students were able to generate and use evidence. First, students were asked to devise an observing plan on how they would test predictions regarding the sun and moon. Most of the students were able to offer mostly complete to beyond complete observing lists. This shows they were able to offer at least some appropriate astronomy observations regarding their predictions. However, exactly 50% of the offered observations lists were mostly complete with students failing to correctly articulate some key piece of information regarding their observations, including exactly what to observe or when to observe. Many students also exhibited inappropriate assumptions regarding the motion of the moon and sun and included this as part of their observing plans. Students need more explicit instruction in these areas of evidence gathering and study design before they can fully conduct appropriate investigations on their own (Donovan & Bransford, 2005; National Research Council, 2012). Thus, this is likely an issue with the curriculum not emphasizing proper observations or explicitly discussing these ideas with students.

Students were also asked to justify their answers during interviews with regards to the sun and moon. The results were mixed with some students stating their observations of the sun and moon and explicitly tying those back to assumptions and ideas they had about the sun and moon in post-interviews. This is an example of the students being able to appropriately use evidence as a means of supporting their answer in ways that go beyond statement of evidence or hearsay. However, some students also showed a greater reliance on simply stating observations, most notably referring only to their planetarium visit as their justification. Though it is appropriate to use observations as a part of a justification, scientific arguments should go beyond stating those observations and the place that the observations were made (McNeill & Krajcik, 2011; National Research Council, 2007, 2012). Students also need explicit frameworks, scaffolding, and modeling of proper explanations with reasoning and justification often being the most difficult for students and teachers to grasp (McNeill & Krajcik, 2007). This is again a problem of the curriculum, as it did not explicitly discuss how to engage in scientific explanation, arguments, and justifications.

5.4.2. Implications for the SMILES Framework

There are no direct ties to the SMILES guidelines regarding student reasoning and both generating and using evidence could be improved through more explicit instruction. However, the fact that three of the four vignettes showed students using justifications that cited the planetarium does suggest they placed a sense of authority on it as a source of information. Traditionally museums have been seen as places of absolute truth and they adopted more didactic authoritative voices in how they presented information (Cameron, 1971). However, modern museum educators warn against this as all information is contextualized and interpreted by the museum for the visitor. Now it is seen as part of the museum's duty to be transparent about their interpretations (Cameron, 1971; Hein, 2006; Hooper-Greenhill, 1992). Museums have also adopted more constructivist views of learning where people construct their idea based on prior knowledge and their own personal context (Falk & Dierking, 2000; Witcomb, 2006). This means the authoritative voice needs to be muted to support learners of diverse backgrounds (Hein, 2006) causing museums to shift toward engaging their visitors in dialogue and critical thought through methods such as asking visitors to leave their own responses, asking compelling and pointed questions, having docents interact with small groups, and using crowdsourcing and social media (Cameron, 1971; Gurian, 2007; Hein, 2006; Yasko, 2007). Justifications of answers that strictly cite the planetarium as a source of authoritative information suggest students are not thinking critically and engaging in the appropriate methods of learning informal settings try to support.

However, planetaria by their nature tend to be more didactic and structured than museums, meaning it is difficult to entirely mute that authoritative voice. Even when planetarium shows are more interactive and participatory, they often are still on a strict schedule, which in turn limits meaningful dialogue during the show. As a result, planetaria may be more likely to imply a sense of authority, resulting in the types of justifications students gave in their answers. This, however, is not necessarily an undesirable in the case of planetaria, which have been ignored in the literature in this regard. Planetaria are particularly well suited for supporting students in making observations through an accurate recreation of the night sky. Students should place authority on the recreation they are seeing. Questioning the information suggests the model of the planetarium is inaccurate and the purpose the visit is not well justified. There is not a need to avoid an authoritative voice in the planetarium, only to support students using the authoritative information properly when justifying their ideas and explanations rather than relying on that authority.

A possible solution is to align the curriculum with scientific practices outlined in the Next Generation Science Standards (NGSS). NGSS emphasizes that students should engage in scientific practices, including asking questions, data collection and analysis, using and generating models, creating explanations, and engaging in argumentation, using computational models, and communicating scientific information (National Research Council, 2012). Some constructivist modes of learning can be supported through these practices. For instance, students can use prior knowledge to plan out which data to collect in the planetarium and how to analyze it when they return to the classroom. Astronomy is also a very model-based science and as discussed in the previous sections, students can work in creating and refining models that can predict and explain observations similar to past astronomers, allowing them to construct their own ideas rather than be told the answers. In working on those models, students can create explanations for why and how their models work and engage in argumentation with peers with finding the most predictive versions, further guiding them toward constructing their own knowledge of phenomena. The planetarium's role is then to act as the source of data collection, where students gather the correct and authoritative facts that are used in other practices such as creating models, explanations, and arguments over an extended period of time in the classroom. These practices can help students take ownership of their data collection and see how to apply the information, allowing them to shift their view of data collected as evidence that supports ideas rather than facts to be blindly accepted.

This issue falls under both principle 1 and principle 2 of SMILES. For principle 1, it goes back to the suggestion in the previous section to add in a chance for students to collect information and review data in the classroom. This supports learning beyond giving students multiple exposures to what they saw during the visit, but supports students in using and reflecting on the authoritative information. Students should have an explicit means of revisiting data collected while at the planetarium in the classroom, but one focused on scientific practices and inquiry skills such modeling, explanation creation, and/or argumentation to make sure students have a means of understanding the importance of *using* authoritative facts and not just blindly accepting them.

For Principle 2, we can further address this in the guideline for teachers to "participate in and model learning in an informal setting." When the curriculum was developed, this was taken to mean applying appropriate listening skills for the more didactic presentation and having students realize they would be taking advantage of the opportunity the planetarium can offer, namely the visualization of a realistic night sky under ideal conditions. However, the modeling in this case should also include the teacher showing students how to properly engage in these scientific practices. Explanations, reasoning, and argumentation are notorious for being difficult for students to master and modeling by teachers has been shown to be effective (McNeill & Krajcik, 2007, 2011). Therefore the teacher should play an important role in helping students properly justify answers with their data collected back in the classroom. This guideline is appropriate to museum settings as well, particularly those that do still offer an authoritative voice. However, modeling and engaging in the practices can also be emphasized in the museum setting where the social aspects so learning are more prominent. Due to the structured nature of the planetarium, it will be necessary, again, to address these practices *in the classroom*.

5.5. Strand 4: Reflecting on Science

5.5.1. Discussion of Results

For this strand, the results were positive with a majority of responses showing students held views of science as a process. Overall, this shows a strong example that students reflected on science as a process and the nature of science as something that is actively done. It is possible that some students had these ideas about the nature of science before the unit on astronomy. Thus it cannot be said for certain this was entirely an effect of the curriculum or of previous teaching.

The curriculum did emphasize specifically that astronomy requires observations of the night sky and this was particularly true in their field trip, as it was presented as a way for students to test their predictions. All of the students chose either agree or strongly agree on the item related to observations being important in astronomy. This suggests that the curriculum did have some effect in the students ideas, particularly how the field trip was integrated into their unit as a purposeful scientific activity and for a chance to make observations.

Additionally, students worked in pairs for all of the in-class activities, including predictions and projects. Beyond the accepted notion that people learn socially, being able to work with others is an important scientific practice. Some of the scientific practices emphasized in the *Framework for K-12 Science Education* can be tied back to the social aspects of science including scientific argumentation and communicating information (National Research Council, 2012). Scientists continually debate, discuss, and present information to one another in order to refine ideas. In the Likert-survey results 88% of students either agreed or strongly agreed on the item related to listening to other people's ideas in science, even if they disagree with them. No student disagreed or strongly disagreed with this statement. Though listening to the ideas of others was not expressly discussed in the curriculum, this shows that students were able to recognize social interaction and discussion as an important aspect of science. Again, a large aspect of this could have resulted from previous instruction with the kids. However, immediately after the curriculum a majority students did hold this idea, suggesting the curriculum did at least further support this notion with the students.

5.5.2. Implications for the SMILES Framework

Multiple guidelines in the first principle of SMILES can be tied to the results for these Likert-items. Observations were not only emphasized because it is an important practice within astronomy, but are tied directly to the students being able to use the planetarium as part of their curriculum. Students were expressly lead to the idea of the planetarium visit having purpose in order to test predictions through observation, thus tying it to the guideline "clarify with the students the purpose and use" of the planetarium visit. Within the discussion of the purpose of the visit, students also discussed the different learning opportunities for observations that the planetarium offered, addressing the guideline "embed the curriculum firmly in a classroom-based unit". This gives some indication these two guidelines were still appropriate for the planetarium setting.

The fact that student responses were very positive with regards to this strand, particularly the item related to observation, suggests that these original SMILES guidelines are appropriate for the planetarium setting. More work may be needed to fully understand this principle and this strand, as it is very little data with which to make any concrete conclusions. However, the results are positive and are at least an indicator that many of the guidelines are useful. Furthermore, the results regarding observations do suggest that using planetaria as a source of data collection, as suggested in the previous section, is positive and an acceptable scientific practice to apply to these field trips.

Students also showed some positive responses toward listening to other people's ideas even when they disagree. This could have resulted from a culture in the classroom prior to the unit. It may have also resulted from students working in groups. Working in groups was a way of addressing the "facilitate formation of autonomous groups" in Principle 2. This guideline has already been addressed in the discussion of strand 1, where there were some weaknesses seen regarding pairing up students. Caution needs to be taken when forming groups to account for the complexities of social interaction, however the results in this strand suggest that having students work with others in some capacity remains an appropriate guideline, though it does need to be shifted to the classroom due to the structured nature of the planetarium.

5.6. Strand 5: Using Tools and Language of Science

5.6.1. Discussion of Results

This strand looks at tool and language use. Students showed several examples of using appropriate tools as part of their project. Tools included protractors to measure out angles, rulers, and the Internet as a reference source. Students were not instructed or taught specifically how to use certain tools but were encouraged to find their own answers through the use of various means that made sense to them. They were given control over how they engaged with and built their projects and made their predictions.

Tool use is a scientific practice that students are expected to learn as part of the *Framework for K-12 Science Education* (National Research Council, 2012). Tools are used specifically for analyzing and interpreting data and critical thinking. They can also be useful regarding social interactions within science, as scientists use a common set of tools that allow them to effectively and efficiently discuss results and interpretations (Brown et al., 1989). Considering tool use was not explicitly addressed in the curriculum it may be advisable in future versions of this curriculum to address more astronomy specific tool use that students can refer to when doing these sorts of projects. These tools would include things such as planispheres, sky maps, telescopes and possibly planetarium software. However, these would require explicit instruction on how to use them and would need to be appropriate to the content being taught.

There were some examples of students appropriately using normative astronomy language after the curriculum. This included appropriate uses of the terms zenith, degrees, and new moon. This suggests that the students were able at least begin to effectively communicate astronomy in an appropriate manner, which is an important skill for scientifically literate people (National Research Council, 2007, 2012). However, not all students used the same language in the post-interviews and some students never used any key words. There were two less common names of the lunar phases, gibbous and quarter moon that only one student ever used. These terms were only mentioned while the students were in the planetarium. It has been shown that effective modes of teaching vocabulary include giving students the definition mixed with context-appropriate use and multiple exposures to the word (Stahl & Fairbanks, 1986). Students were introduced to the terms in an appropriate astronomy context in the planetarium. However, they were only given specific definitions for the terms zenith and new moon, which were more frequently used in the post-interviews. More exposure and explicit statements of definitions may have helped more students adopt astronomy appropriate terminology.

The use of the term degrees was an interesting case, as many students implied degrees without explicitly stating the term. A total of 5 students after the unit used the correct number in degrees to describe the altitude of the sun without using the term “degrees”. The term was either unknown to the students or simply implied. The term degrees was never intended for students to use as the numbers were only emphasized to note differences in the sun’s altitude while in the planetarium. The use of degree markings, however, was noted and used by several students. Had the term degrees been more frequently used and emphasized in the planetarium, more students may have also included the unit along with the numbers they repeated back.

5.6.2. Implications for the SMILES Framework

In the case of the language and tool use, some students were able to appropriately use both. With tools, the use was not expected of them, but they relied on their autonomy of the projects and predictions to use what worked in a way that made sense to them. This addresses the second principle and the guidelines specifically those related to giving students choice and control in their learning episodes and providing a learner-centered approach where students are able to find information on their own. Again, these guidelines are meant to guide how the field trip is utilized in the unit and not the formal classroom side of the curriculum. However, choice, control, and autonomy were offered to the students in the classroom and had little adverse effect, suggesting it is appropriate to move these aspects of the guidelines from the informal setting to the classroom when the informal setting is more structured and didactic in nature.

Students also showed positive results regarding language use, but they could have benefitted from more exposures and introductions of explicit definitions. This addressed the first principle of SMILES and the guidelines related to preparing students for the concepts they would be exposed to during the visit. However, an important aspect of content is the vocabulary and key terms students will hear and use while at the informal space. Though some terms were emphasized and discussed with students before, during, and after the show, not all were sufficiently addressed. Students should be prepared for the language as well as concepts that help them become more efficient in communicating ideas. Thus, it may be useful to address the preparation of student vocabulary more explicitly in SMILES framework.

5.7. Strand 6: Identifying with the Scientific Enterprise

5.7.1. Discussion of Results

This was a generally positive example of students identifying with the scientific enterprise as a majority (61%) of students reported positively to the items related to this strand. For specific items, a majority of students disagreed or strongly disagreed that only astronomers can use and understand astronomy. Additionally, 72% of students agreed or strongly agreed on the item stating that they can understand astronomy. Overall, the responses gave a good example that students do identify with the scientific enterprise and do not see science as something that is unattainable.

Though the results were very positive, the majority of positive responses in this case are not as strong as the other Likert survey results, with an almost equal number of responses falling under agree and neutral. One explanation is that students felt that they could not understand astronomy while other non-astronomers might be able to. There are also very few statements that were given, so effects from statements such as "I would like to be an astronomer" may be offering significant bias to the results. These students are young and may not know what they want to do for a career yet, causing larger bumps in the neutral category. The overall positive results could also be a result of earlier teaching and views the students already had prior to the curriculum. However, it is not unreasonable that the curriculum played at least a small role in these answers as discussions in the class emphasized the usefulness of astronomy to their own lives.

5.7.2. Implications for the SMILES Framework

This strand is primarily addressed through the guidelines of Project-Based Learning (PBL). Specifically, PBL states that curriculum and driving question should be relevant to students' everyday lives (Krajcik & Blumenfeld, 2006). As a result, students were introduced through discussion why learning astronomy could affect their life and be useful to them. This does not mean, however, that this strand cannot be connected back to SMILES. For, instance, an important aspect of SMILES is in the first principle and its guideline to clarify the purpose of the visit with students. Though talking about how astronomy is relevant to their own lives is not directly connected to the purpose of the visiting the planetarium show, it did show a more overarching sense of purpose for the whole curriculum. Since students reacted positively to astronomy as something they could use, this suggests that this guideline is still relevant and important for planetarium visits.

5.8. Revisions to SMILES

There were examples of each of the 6 strands of informal learning observed during the implementation of curriculum. Since the curriculum design had specific ties to the SMILES framework, this suggests that SMILES and other similar frameworks are appropriate starting points for use with planetaria. This is not unexpected as planetaria are still informal learning environments that are in very different contexts from where students usually learn and offer unique experiences that have shown to have both positive affective and cognitive effects for students (Lelliot, 2007; Plummer, 2007; Ridky, 1975; Small & Plummer, 2010; Sunal, 1973). Though there were many positive results, there were some weaknesses observed in the examples as well. The examples and weakness implied that some revisions to the SMILES framework might be necessary.

Below each principle of the SMILES framework is discussed with a focus on suggested modifications. The revised framework will tentatively be called the School-Planetarium Integrated Curriculum Approach (SPICA), to distinguish it as a framework that is specifically geared towards integrating planetarium and classroom learning. It should be emphasized that these changes are only *suggested* and exploratory based on the results from this dissertation and should be tested further to confirm their usefulness and make a more comprehensive framework for use with planetaria. The principles are held in tact and unchanged from SMILES. There are just some additions and modifications to guidelines that are made more explicit with regards to planetaria. Table 5-1 (pg. 255) summarizes and highlights the suggested revisions by underlining any differences in the middle column.

In the following sections it will become clear that many suggested changes have implications for any informal setting, including planetaria *and* museums. However, how they are operationalized specifically in a planetarium setting may look different because of the more structured nature of planetaria. Therefore, further suggestions of how we can best can address the guidelines in planetaria and similarly structured informal environments will be discussed. A third column in table 5-1 (pg. 255) will list these suggestions for planetaria and similarly structured environments.

Finally, it should also be noted that not all guidelines were explicitly studied in this dissertation or had implications regarding them in the results. Since the curriculum can be considered successful to the extent that there were examples of all 6 strands seen, guidelines not explicitly discussed are assumed to remain unchanged. Only those guidelines that are revised or have additional suggestions will be discussed in any detail.

5.8.1. Principle 1: Integrating School and Museum Learning

This principle deals with integrating school and museum learning. The guidelines speak primarily to how the visit should fit into the classroom curriculum in such a way that it is actually a part of the unit. Guidelines include embedding the museum visit in the curriculum, with the visit toward the end of the first half of the curriculum, discussing with students the purpose of the visit and learning opportunities that are unique between the formal and informal setting. Guidelines also suggest that students' prior knowledge is considered as well as their prior experiences with the venue they will be visiting.

Most of the guidelines in this principle remain unchanged. Embedding the planetarium visit in the unit is particularly useful as students clearly mentioned the planetarium throughout their post-interviews as a source of their ideas, showing they transferred knowledge across contexts. However, there are some suggested additions. The first regards the guideline to "plan and prepare with students the overall concepts to be investigated during the visit." Students did show positive results regarding the content learning, suggesting that this guideline at least does not need to be changed currently regarding concepts. However, the results regarding language (strand 5) suggest that this should be expanded to also include the language students may encounter as some students did not adopt key terminology when talking about the sun and moon (e.g. degrees, gibbous moon, quarter moon). Amount of exposure and context of that exposure to certain important key terms of astronomy may have contributed to this. As a result, this guideline should reflect language preparedness in addition to the concepts and read as "plan and prepare with students the overall concepts *and language* to be investigated during the visit."

Language is not a unique problem to planetaria and could also be addressed in any informal setting. However, without extensive social interaction allowed or the presence of labels in the planetarium, it is more important for students to be exposed to key vocabulary prior to the visit in the classroom so they can have a chance to use the terms. For instance, the curriculum in this dissertation should have more explicitly discussed the names of the phases and degrees before the planetarium field trip. In a more generalized form across structured and scripted shows it could be useful to offer teachers the show's script or at least a guide that highlights key terms that students to be exposed to prior to the visit along with definitions and descriptions of how they will be used. Then teachers can then use the terms in class, introduce definitions, and give students some context for how the terms will be used in the show.

The results for strands 2, 4 and 6 also specifically addressed the guideline "clarify with the students the purpose and use of students' museum learning particularly indicating how they will use the information at school after the visit." Students were given a specific purpose in the sense they knew they would make observations that are important for astronomy, how they would use the content in projects after the visit and also held discussions on the purpose of the visit beyond school and into their everyday life. Since students did show positive results for all three of these strands, this particular guideline should remain unchanged.

However, within strand 2 students clearly missed out on key details and strand 3 showed that students relied on the authority of the planetarium's information as a source of justifying answers. There should be a guideline that states students should explicitly collect data while at the planetarium and revisit it in the classroom in a way that explicitly addresses scientific practices of the NGSS. Post-activities that incorporate explicit use of collected data will help ensure multiple exposures to those ideas to help solidify normative ideas to help address weaknesses in strand 2. Focusing on practices specifically that can emphasize use of the data in those post-activities, such as creation of models, explanations, and arguments, can also help ensure students do not justify answers based on the authoritative facts from the planetarium in order to address strand 3.

To support ownership and the principle 1 SMILES guideline of "plan and prepare with the students the overall concepts to be investigated", it is possible to allow students to design the data collection sheet in the classroom beforehand. Considering that students had some minor difficulties creating appropriate observation protocols (also strand 3) without explicit instruction during this curriculum, teachers may want to have an idea of what students should collect or museums can provide a sample data collection sheet to help guide students toward how and what data would be appropriate to collect. Ideally students should collect data in the planetarium itself during the show. However, in some cases it may difficult in many planetaria to collect information, students should have a chance to collect information as soon as possible after the show, preferably while still at the informal venue so they do not forget important details.

The use of data collection in the informal setting and applying practices in the classroom is relevant to museum settings as well because museums can also have an authoritative voice that students should not use for justifying answer. Furthermore, helping students collect data in museums has already been done successfully. However, the data collection in museum settings has been guided by exploiting the choice and control characteristics of museums settings. This, again, does not address the structured nature of planetaria. However, choice and control are a larger part of principle 2 and this problem in particular is addressed in the guideline "Facilitate a range of learning approaches and strategies which complement the informal setting and optimize use of all learning opportunities provided." How to address this difference more specifically in planetaria settings will be discussed in the next section.

5.8.2. Principle 2: Providing Conditions for Self-Directed Learning

This principle deals with providing conditions for self-directed learning and offers guidelines on how to structure the museum visit. Guidelines include fostering curiosity through choice and control of learning episodes, allowing students to find information in their own area of inquiry, encouraging students to generate questions during the visit, facilitate formation of autonomous groups, facilitate a range of learning approaches which complement the informal setting, and having teachers participate in and modeling learning in the informal setting.

This particular principle was initially the most problematic for planetaria as they are different learning environments from museums. The structured nature of shows can result in lack of personalization and choice for students. It also limits the ability for students to find their own area of inquiry while at the planetarium. Thus, guidelines related to choice, control, and social learning had to be addressed in the formal context back in the classroom rather than the intended informal environment during this dissertation through the use of projects and project-based learning.

The projects were a successful aspect of the curriculum and were added to address guidelines related to choice, control, and question generation. The results from strand 1 showed that students did engage with the topic on deep levels and did ask and seek out answers to thoughtful questions while working on the projects. Not all groups engaged in the same way and level and there were some students that perhaps needed extra support. However, the majority of students studied showed engagement indicative of interest. The results of strand 5 also showed students autonomously and productively working in the formal classroom guided through their appropriate and spontaneous use of tools. This suggests that addressing choice and control into the classroom was a positive initial change to the guidelines for students. Thus, guidelines in SMILES should be made explicit that learner-centered approaches should be addressed in the formal setting of the classroom rather than the informal context in cases with planetaria or any more structured informal setting that does not allow for choice and control in learning. This was a simple initial change, but one that does distinguish the planetarium and museum settings and permeates through several guidelines in this principle.

This principle also suggests that students are allowed to form autonomous groups while on their visit. However, this is not possible in the planetarium. In order to facilitate the social learning this is meant to promote, students were put in groups in the classroom. However, the teacher was more comfortable choosing the groups to promote a more productive environment, meaning the groups were not entirely autonomous. Overall, the decision to group the students herself did not seem to have a large negative effect on social learning as most students positively responded to items on the survey regarding listening to others' ideas and engaged appropriately while working on projects. However, there was one group that did not work well together during the projects and this in turn negatively affected their engagement. Thus, to help mediate the potential negative effects and support student interest and engagement in the classroom, it may be desirable to allow students to work in heterogeneous groups with each student adopting a specific role (Schunk et al., 1996). However, the teacher does need to use considerable judgment in the classroom to maintain an effective workspace for everyone. Thus, the guideline addressing autonomous groups should be changed to reflect this judgment teachers need to make when these guidelines are implemented in the classroom environment.

Principle 2 also addresses how to model learning for students in the guideline "Participate in and model learning in an informal setting." The results of strand 3 suggest some revisions to this guideline. The students did use the authority of the planetarium as a source of facts as a sole justification for answers rather than connecting them to a larger idea. In the previous section, it was suggested that students should participate in scientific practices that encourage them to construct their knowledge and use that authoritative information effectively to justify ideas and not blindly state facts. Teachers can play an important social learning role by participating in and modeling for students how to engage in those scientific practices as this has been shown to be effective in the past (McNeill & Krajcik, 2011). This includes practices such as how to appropriately collect and analyze data, make models and predictions with that data, and create explanations and arguments using the data as evidence to properly support ideas.

Again, the idea of teachers modeling how to use data and think critically about collected information is not unique to the planetarium setting and informal environments are particularly useful for collecting data. However, the structured nature of the planetarium does have some implications for the practice of data collection that can be addressed as part of the guideline "supporting students in learning strategies appropriate to the setting". Using the museum to collect information through worksheets and mobile devices has been shown to be useful in the literature (Cahill, Lo, et al., 2011; Griffin, 1994). These methods have exploited the characteristics of choice and control in museums in supporting students in collecting information. However, planetaria are structured and often have key points for students to grasp. As a result, any method of collecting data should be similarly structured in the show-based environments to help students more effectively gather important information that the structured show offers. To further support social learning, students can also work together in small or whole class groups in the classroom to review what was collected and make sure they agree to further ensure they collected the correct information.

5.8.3. Principle 3: Facilitating Learning Strategies Appropriate to the Setting

Principle 3 addresses how to prepare students to learn across the settings. It includes guidelines such as providing students information about the informal setting, discussing appropriate learning strategies for the setting, allowing students a chance to orient themselves to the site, and anticipating variations in concentration by allowing periods of mental and physical rest. Most of these guidelines remain unchanged as many students have been shown to need orientation to planetaria and how to learn from them before (Ridky, 1975; Sunal, 1973). Previous work has suggested that students visit the planetarium multiple times for this orientation. However, the suggestion from museum literature to show students pictures and maps was used in this dissertation and did not seem to have any adverse effects. Thus, this is a useful means of preparing students. Other possibilities that could be tested for show-based immersive environments like planetaria would be to show pictures from the actual show rather than the space or clips, similar to a film trailer, as a means of preparing students.

Additionally, students were oriented to the planetarium space while on site to address the guideline of allowing students a period of orientation at the beginning of the visit. This was done by showing them where the direction, horizon, zenith, and meridian line were before they even began, giving them slightly more exposure to these ideas/visualization. Students started adopting the term zenith and referred to the visual numbers on the meridian line shown in the planetarium for the height of the sun frequently in the post-interviews. This suggests that orienting students to the space the show takes place through language and visuals may be useful. Thus, in a more generalized sense for structured shows it may be useful to orient students to the parts and purpose of the room, particularly those that have specialized visualizations or equipment.

The guideline related to anticipating variations in concentration is slightly more difficult to address in the planetarium. First, students are in a planetarium for a short period of time and it is a more structured environment. In museum settings students can take breaks when they need to while on a visit. They cannot do the same thing in the planetarium. Instead the show has to be specifically designed to help reduce mental fatigue. This was kept in mind by having the last portion of the show address a topic that was unrelated to what they were studying in their driving question. However, students seemed to do poorer on questions and language related to the moon as shown in the results from strands 2 and 5. The moon was discussed in the second half of the planetarium show and the students may have become fatigued by that point in time and confused ideas between the two halves. Thus an additional guideline should be added to address this specific aspect of planetarium shows. It may be beneficial to limit the show's main topic to one major area such as diurnal motion of celestial objects, celestial motion of the sun and its seasonal changes, or the moon's motion and phases. Exactly what should be the limit will need to be tested for different shows and left to the judgment of the planetaria operators. If additional topics are introduced, however, the show should delineate it from the previous portion of the show to indicate to students that the topic is switching. Possible ways this could addressed are with a visual aid, a small intermission to ask questions, or giving students an outline or agenda of what will be addressed.

5.9. Summary

The SMILES principles and guidelines offer excellent and appropriate starting point to be used with planetaria as there were examples of each strand of informal learning observed. This should be expected as the SMILES framework was designed to be flexible and usable with a variety of informal learning environments. This dissertation's intention was to suggest more specific modifications for the guidelines appropriate to the planetarium setting. Some of the recommended changes are applicable to any informal environments however. So implementation and instructional implications for planetaria and similarly structured informal environments were also discussed. An overview of guideline revisions and suggestions can be found in Table 5-1 (pg. 255) along with the original SMILES guidelines.

There were some changes to the SMILES guidelines of principle 1 that were suggested that could also easily be addressed in any informal setting. First, students did not widely adopt three of the five key astronomy terms in the curriculum. Further exposure to these terms may be needed and it was suggested that students prepare not only for concepts but language before a visit to the planetarium. Since language is not a unique consideration for planetaria, it was further suggested that teachers are given scripts of planetarium shows or at least some outline of the show that highlights terms students will hear and the context in which they are used.

In addition to language, it was suggested that students are given a chance to collect data from the planetarium show and explicitly review on that information in the classroom in the context of scientific practices. This will help ensure students are exposed to ideas seen while on the visit multiple times to help them remember key details as they reflect on the information. Tying that reflection to scientific practices can help students gather a sense of why this information is important, how it fits into a larger picture, and how to properly use authoritative facts they gain from the planetarium to justify answers. Since planetaria are more likely to have an authoritative voice, students should focus specifically on practices such as argumentation, explanation, and model creation to ensure they can apply their knowledge and not just parrot back facts. Additionally, students should be allowed to create their own data collection sheets to help address ownership. It was also suggested that those data sheets are structured to match the topics and key information found in the show. This matches the planetarium's structure and ensures that students catch key details they many need in developing models and argumentation in the classroom.

For principle 2, there was a major noted change that affected several guidelines. This was that students should be supported in their choice, control, and social learning in the classroom rather than the informal setting since these characteristics are limited in the planetarium. This was an initial change to SMILES and addressed in the form of projects. Students had their interest and excitement sparked by the planetarium as seen in positive Likert-results and it was sustained by allowing choice and control in the classroom during the projects, as seen by students deep engagement.

Allowing social learning in the classroom was also generally positive, but does require some additional support with planetarium settings. Since students are in a more confined space of the classroom, other dynamics are at play. Teachers, such as Mrs. Bishop in this study, may be more comfortable deciding to maintain order in the classroom. As a result, it is suggested that students are grouped by heterogeneous ability and given specific jobs to encourage ownership and motivation when it is not practical to give them full choice with whom they work.

Since, scientific practices are being emphasized more in the Next Generation Science Standards, it was also suggested that a modification to the guideline related to teacher modeling address this shift more explicitly. Additionally, supporting these practices as much as possible is useful as they can help students justify ideas and answers appropriately with authoritative facts they gather at an informal space. Practices that are well suited for extended attention in the classroom that can help students apply their knowledge include analyzing data, modeling, argumentation, and explanations.

For principle 3, it was noted that students began confusing ideas from the first half of the show with those in the second half. Thus for the practical aspects of the show design, a suggested revision was that shows should minimize the topics addressed. This is particularly true for shows given by multiple presenters of different ability levels. Multiple topics may be possible, but it is then suggested that the show delineates the change in topic to make students aware that they will be changing contexts. It was also suggested that it might be helpful to give students a quick outline or agenda at the beginning of more structured shows to help mark out those shifts.

Table 5-1 Revised SMILES Guidelines and Implementation Suggestions (cont'd on next page)

SMILES PRINCIPLE	SMILES Guidelines	SPICA Guidelines *(Modifications to SMILES underlined)*	Implementation Suggestions for Planetarium/Structured Informal Environments
INTEGRATE SCHOOL AND MUSEUM LEARNING	• Embed the museum visit firmly in a classroom-based learning unit, with the museum visit preferably occurring toward the end of the first half of the unit's program; • Discuss with the students the different learning opportunities offered by the school and museum and how they can best be used to complement each other in the particular topic being investigated; Plan and prepare with the students the overall concepts to be investigated during the visit; • Consider the students' prior experiences of museums, the particular venue, the topic and the learning approach, when preparing for the visit; • Clarify with the students the purpose and use of students' museum learning particularly indicating how they will use the information at school after the visit.	• Embed the planetarium visit firmly in a classroom-based learning unit, with the visit preferably occurring toward the end of the first half of the unit's program; • Discuss with the students the different learning opportunities offered by the school and how they can best be used to complement each other in the particular topic being investigated; • Plan and prepare with the students the overall concepts to be investigated <u>and language used</u> during the visit; • Consider the students' prior experiences of museums, the particular venue, the topic and the learning approach, when preparing for the visit; • Clarify with the students the purpose and use of students' planetarium learning particularly indicating how they will use the information at school after the visit. • <u>Incorporate some explicit and consistent means of allowing students to bring information back to the classroom to revisit, preferably recording information during or as soon as possible after a show.</u>	• Address scientific practices in the classroom component of the curriculum, particularly data collection, argumentation, explanation, and creation of models • Provide a copy of the script or a guide for shows to teachers that include relevant vocabulary words addressed in the show and the context in which they are used (e.g. zenith, horizon, phase names) • Have students plan out their investigation by creating a data collection/observation log sheet to be used during or immediately after the show
PROVIDE CONDITIONS FOR SELF-DIRECTED LEARNING	• Foster curiosity by providing opportunities for students to have choice in their specific selection of learning episodes and sites; • Use a learner-centered approach where the students are finding	• Foster curiosity by providing opportunities for students to have choice in their specific selection of learning episodes and sites <u>in the classroom</u> • Use a learner-centered approach where the students are finding information on their own area of inquiry <u>in the classroom</u>, within the parameters	• Make the data collection structured rather than open ended to make sure students do no miss any key details • Allow group discussions to compare collected data

	information on their own area of inquiry, within the parameters set by the teacher; • Encourage students to generate questions and use their museum visit to stimulate interest in finding out more about the topic; • Facilitate formation of autonomous groups of students each accompanied by an adult who has been briefed on the program, and/or has some expertise in the topic area; • Facilitate a range of learning approaches and strategies which complement the informal setting and optimize use of all learning opportunities provided • Participate in and model learning in an informal setting.	set by the teacher; • Encourage students to generate questions in the classroom visit to stimulate interest in finding out more about the topic • Teachers use their best judgment on how to group students in the classroom according to heterogeneous ability levels, being aware that some groupings may have negative influence • Facilitate a range of learning approaches and strategies which complement the informal setting and optimize use of all learning opportunities provided • Participate in and model learning in an informal setting and classroom, including scientific practices that emphasize thinking critically about information gathered and justifying answers using that information	• Model scientific practices that particularly complement planetarium and structured informal environment learning in the classroom such as data collection and analysis, models, explanations, and argumentation
FACILITATE LEARNING STRATEGIES APPROPRIATE TO THE SETTING	• Provide students with information about the setting – its purpose, content, methods of operating and how displays are prepared; • Discuss with students the learning strategies and opportunities available and the skills required to use them; • Allow a period of orientation at the site; • Anticipate variations in students' concentration and depth of examination of exhibits over the period of the visit. Allow both physical and mental rests.	• Provide students with information about the setting – its purpose, content, methods of operating and how displays are prepared; • Discuss with students the learning strategies and opportunities available and the skills required to use them, • Allow a period of orientation at the site; • Anticipate variations in students' concentration and depth of examination of *show* over the period of the visit. Allow both physical and mental rests. • Focus on one major topic or delineate shifts in topic during the show to avoid confusion and mixing up of ideas	• Show students' stills or a "film trailer" of the show to be seen. • Make sure students are aware of the space itself, including purpose of special equipment and visualizations • End show on irrelevant information to purpose of visit • Give students an agenda or mark out changes in topic through intermission/asking question/visual aid

Chapter 6

CONCLUSION

6.1. Overview

This chapter summarizes the work done in this dissertation and looks at how it can be applied more broadly. First, the Next Generation Sciences Standards, introduced while this dissertation as being written, are discussed. This offers a sense of how this work can have impacts that will last into the coming years. I will then summarize the results and main conclusions of the dissertation. Next I will look at the limitations in the results and study design of this dissertation and related future work that should be done to address those limitations and other issues brought up throughout the thesis. Implications of this work that go beyond the narrow realm of planetaria will also be discussed.

6.2. Next Generation Science Standards

The *Next Generation Science Standards* (NGSS) were developed while this dissertation was conducted and have been mentioned throughout. This section will look at them a little more closely, as they will be the basis for sweeping changes in standards in coming years. I will discuss how they can be addressed with field trips and by integrating informal and formal environments, with a focus specifically on planetaria.

In the past, science standards have focused on assessing students on their content knowledge and their inquiry skills as discrete entities. NGSS recognizes that science is not made of separate skills and knowledge, but instead there are practices of science that are blended with disciplinary core ideas (DCIs) as discussed in the *Framework for K-12 Science Education* (National Research Council, 2012). Scientific practices outlined in NGSS include:

1) Asking questions and defining problems
2) Developing and using models
3) Planning and carrying out investigations
4) Analyzing and interpreting data
5) Using mathematics and computational thinking
6) Constructing explanations and designing solutions
7) Engaging in arguments from evidence
8) Obtaining, evaluating, and communicating information

Assessment is guided by performance expectations that include making sure students can simultaneously display appropriate DCIs combined with a relevant scientific practice. For instance, a DCI of knowing patterns of the sun's motion that result in the day/night cycle can be blended with the third practice, planning and carrying out investigations to result in the NGSS performance expectation of "use observations to describe patterns of objects in the sky that are cyclic and predicted."

Combining informal and formal learning settings through field trips offers a particularly useful means of supporting these performance expectations. Field trips to informal environments usually last less than a school day, limiting how much learning can immediately happen there. However, informal environments are filled with opportunities to engage in authentic observations and data collection and experience immersive settings that can help students visualize concepts in ways that are not practical in school settings (National Research Council, 2009, 2010). For instance, students can see an accurate recreation of the night sky in the planetarium or get up close and personal with a T-Rex skull in a Natural History Museum. Students can use collected information back in the classroom and engage in other practices such as analyzing data, using information to create predictive models, creating explanations of observed phenomena, and engaging in argumentation and peer critique of their ideas to name a few. The classroom environment allows students the extended period of time necessary to address these practices that can often take several iterations to complete, all while centered still on a core idea in science with facts and information gathered from the informal setting.

Planetaria in particular can support can support astronomy performance expectations as seen in this dissertation. The curriculum focused primarily on helping students use observations to describe several astronomy DCIs such as patterns in the sun and moon's motion, seasonal differences in the sun's motion, and patterns in the lunar phases. These topics were emphasized because planetaria are particularly well suited for students to make observations of the night sky in a convenient and accurate way, addressed in practice 3. Therefore, the blended knowledge emphasized was "use observations to describe patterns of objects in the sky that are cyclic and can be predicted". Students were also expected to create explanations of their projects and how they worked and present them to the class, meaning they were expected to address science practices 6 and 8 over several days in the classroom. This curriculum on the whole was short, but could easily be expanded to include more practices and DCIs that are more 5th grade appropriate according to NGSS while still appropriately using the planetarium visit.

A performance expectation for students in the January 2013 release of NGSS for 5th grade that could be addressed through an extended curriculum is to "use a model of the relative positions and motion of the Sun, Earth, and moon to describe the observed pattern of daily changes in length and direction of shadows, day and night, and the phases of the moon." This expands to have students appropriately use models (practice 2) of the solar system to describe and predict the observed patterns from the planetarium. Students could possibly develop their own models to try and explain all of their observations from the planetarium. This in turn can support students in scientific argumentation in deciding how to better their models or simply in appropriately explaining ideas that they have through scientific principles. This results in very authentic practices similar to how modern understandings of solar system came to be through testing models against observations. In this case, the planetarium field trip is used as the word *field* implies. Students are going out in the field to gather observations and data specifically to bring back and discuss, model, and analyze in the classroom. This is not dissimilar to an astronomer travelling to a telescope in remote mountains to collect data and then come back to their office to apply that data to a larger problem in science.

The planetarium itself could also be used differently in regards to modeling. A difficulty in helping students understand astronomical concepts is that our models are often from a bird's eye perspective, but our observations and historical work has been Earth-based. Therefore students have to transfer ideas between two different references frames. Digital planetaria in particular are well suited for helping students traverse these reference frames by allowing them to smoothly transfer between the two. To give one major example, students need to be able to understand a model of our solar system that results in the phases of the moon seen to address part of the expectation discussed in the previous paragraph. To do this, students can start with the full 3-dimensional environment of the dome to see the night sky from Earth, but then fly above the planet at that same moment in time to see how the Earth/Sun/Moon are aligned to result in that phase. Students can gather data of the actual sky or in the planetarium, but also spend time considering the specific models involved in the show in a way that cannot be recreated as easily in the classroom.

The implication here for supporting this blended knowledge is to use the field trip in the original sense, as a *field* trip. The students should be using the opportunity at the planetarium or similar setting to gather data as a scientist going out into the field would do. Findings in this dissertation resulted in similar suggestions of focusing planetarium field trips on the practices in the classroom and using the planetarium visit itself as a means of collecting information. This is not limited to the planetarium, but this curriculum offers one means of doing this for astronomy In the next sections I summarize the dissertation, including those findings. Alternatively and more specific to the planetarium setting itself is to use the unique immersive and visualization abilities of the planetarium setting to help students transfer between an Earth-based and space-based reference frames to help students in considering and contemplating models that explain observations.

6.3. Summary of Dissertation

The goal of this dissertation was explore how we can best utilize field trips to planetaria as part of formal astronomy curricula. There has been a tremendous amount of work on integrating formal and informal learning in recent years. However, most of this research has focused specifically on museums and similar institutions like zoos and aquaria while completely ignoring planetaria. This is problematic because planetaria are different in nature from museums. Museums are characterized by choice, control, and social interaction while planetaria are characterized by dark rooms, confined spaces, and structured or scripted shows. This is not to say planetaria cannot allow choice, control, and social learning, just not to the same extent as museums. However, planetaria are still engaging out-of-school experiences for students, so previous research should still apply to them to a large extent. We may just need to modify some of those lessons learned to address the more structured nature of planetaria.

This dissertation attempted to address this gap in the literature by creating a curriculum based on existing guidelines from previous research summarized in the School-Museum

Integrated Learning Experiences in Science (SMILES) framework. The SMILES framework is split into three principles, each with a set of guidelines (summarized in Table 2-1, pg. 21). The first principle focuses on the fact that the visit needs to be embedded in a curriculum in order to support learning across contexts. Guidelines address making sure students plan and prepare for their visit, understand the purpose of their visit, and know how they will use information afterwards. The second principle addresses choice, control, and social learning which are more prominent in museums than planetaria. The guidelines recommend that while at the museum students are allowed choice and control in their learning episodes, encouraged to ask questions, to work in autonomous groups, and the teacher models in how to appropriately learn in informal settings. However, since these characteristics are difficult to address in planetaria, these guidelines were addressed in the created curriculum in the classroom setting. The third principle recognizes the effects of the physical environment on student learning. The guidelines address novelty of the space and its negative effects on the cognitive engagement with content. Furthermore, the guidelines recognize that people can become cognitively and physically fatigued so it is important to allow periods of rest.

The "success" of the curriculum was judged by the presence of the six strands of informal science learning (National Research Council, 2009, 2010). These are goals of informal science learning that address the scientific skills and knowledge students should have. Four of the six strands stem from formal learning goal, so they are applicable across contexts. Strand 1 addresses a need to motivate students by “sparking interest and excitement”. Strand 2 is the most the most basic goal of science education, which is to make sure students “understand scientific content and knowledge”. Strand 3 is helping students “engage in scientific reasoning”, which includes making sure students can justify answers and generate evidence necessary to test predictions. Strand 4, “reflecting on science” addresses making sure students understand that science is a process and not a collection of facts. Strand 5 stems from the collaborative nature of science where common language and tools are used. Thus we need to support students in “using the tools and language of science”. Finally, strand 6 deals specifically with making sure students “identify with the scientific enterprise” where they feel as if they are a part of science and science is relevant to their own lives.

These components resulted in the research questions addressed in this dissertation. The first is “What examples of the 6 strands of informal learning are seen during the implementation of a SMILES-based curriculum that integrates learning across planetarium and classroom contexts?”, which addresses the question of how successful is SMILES when applied to planetarium settings. The second question, “How do the examples of the 6 strands of informal learning suggest revisions to the SMILES framework in order to be more usable with planetaria?” looks at the recommended changes to the SMILES framework when applied to planetaria.

The SMILES curriculum was used to create a curriculum for students focused on apparent celestial motion and lunar phases, as this is something planetaria can support learners in very easily. This is usually taught in the state of Michigan between 4th and 5th grade, so I worked with one class of 5th grade students, 25 of whom had signed permission from their parents to participate in the study. The curriculum spanned approximately 13 hours of instruction, and was taught according to the students’ usual schedule of science 3 days a week for an hour each day. Of those 13 hours, approximately 12 were in the classroom and approximately one hour was in a small digital planetarium at a local natural history museum.

The SMILES based curriculum focused on apparent celestial motion and had the students answer the question "How can we use the sun and moon to tell time?" To prepare students in for concepts they would see at the planetarium, they reviewed altitude and azimuth coordinates in qualitative terms, made predictions related to the lunar phases and position of the sun at different times of the day and year, and created lists of observations needed to test these predictions. Students also discussed how it would be impractical to test all of those predictions in a school year, thereby introducing the purpose of a planetarium visit to the students. The planetarium visit allowed students to observe the positions of the sun and moon to test their predictions and then ended on a “star talk” unrelated to apparent celestial motion to account for possible fatigue. The post-visit included re-doing predictions and ranking activities to help them reflect on what they learned. They also spent a majority of their post-visit time working projects on devices to use the sun and moon to tell time. Projects were added to address principle 3's goals of choice and control and social learning in the classroom since it was more difficult to address in the planetarium setting.

Data was collected and analyzed to address each strand of learning to check for examples seen of each. A five-point Likert-scale survey was given to students, with 4 items each relating to interest and excitement (strand 1), students ideas of science as process (strand 4), and students ideas of science in their life (strand 6). A total of 25 students were given the survey and percentage of responses by Likert point was aggregated across all 4 items per strand was calculated to find trends. Semi-structured interviews on students ideas relating to topics on the sun and a moon’s apparent motion and lunar phases were conducted a week before and after the unit with N=10 students. During the interviews, students were also asked to justify their answers. The interviews were used to code the level of accuracy of student ideas (strand 2), characterize their ability to justify answers (strand 3), and describe how they used key astronomical terms zenith, degrees, gibbous moon, quarter moon, and new moon (strand 5). Audio and video recordings of the N=9 students groups working on their projects and their predictions were used to describe how students used tools in relation to learning astronomy (strand 5). The recordings of N=4 students groups working on their projects were also used to conduct mini-case studies that characterized engagement as a proxy for interest and excitement, as choice can be tied to these emotions (strand 1). Finally, lists of observations students made to test predictions were coded for how appropriate and complete they were regarding generation of evidence (strand 3).

The results for strand 1 were generally very positive. Likert surveys were heavily skewed toward strongly agree and agree, with no responses of strongly disagree. This suggested that the students were interested and excited in the unit. Additionally the planetarium visit was only marked as strongly agree and agree, suggesting it played an important and positive role in sparking interest for the students. In primarily three of the four mini-case studies, several types of engagement consistent with interest were noted of the. These included perseverance through problems and disagreements, asking thoughtful questions, expressing pride, curiosity, mindful discussion, seeking help, and taking initiative. There were also some behaviors that suggested lack of engagement with students being off-task including dancing, and napping. Some off-task behaviors are to be expected to some extent in any normal classroom though, especially when students are left to work autonomously (Lee et al., 1999). One group, however, seemed to really struggle to engage meaningfully with the project, sticking to surface level aspects such as painting and never taking the project seriously. In this group, one member was dominant and dismissed her partner's attempt to think more deeply about a topic, resulting in the partner being off task. They also struggled with the content, suggesting that their lack of engagement came from not understanding the project and needing additional support in the classroom.

Strand 2 also showed some strengths and weaknesses in students' ideas relating to apparent motion of the sun and moon and lunar phases. Students were asked about six topics in the interviews, with three related to the sun in the sun (diurnal motion of the sun, sun's altitude at local noon, seasonal differences in the sun's path) and three related to the moon (diurnal motion of the moon, visibility of the moon during the day, and lunar phase cycle). The major findings were that students were able to grasp "big ideas", particularly about the sun. They correctly stated by the post-interviews that the sun moved in an arc from east to west, never goes through zenith, there are differences in the sun's seasonal path, and the moon changes shape over a 28-day cycle. However, details were often omitted or stated incorrectly such as the sun reaches its highest point toward the North, the seasonal rise and set positions of the sun, or not fully describing all of the phases. This suggests that students needed some additional exposure to normative facts during the curriculum. Students also introduced more mistakes regarding the moon that were not present in pre-interviews. For instance, in pre-interviews students simply stated the moon was visible during the day. In post-interviews they stated it depended on the season or time of day for when it was visible in the day. Students also started describing the moon's motion as a change in angular distance from the sun during the phase cycle when they were asked about the diurnal motion. These difficulties seen with the moon topics could be from exposure of ideas, as they were did not address diurnal motion of the moon prior to the planetarium visit. The placement toward the end of the planetarium show when students may have been fatigued may have also confused students to mix up ideas between the two halves of the show as well.

For reasoning addressed in strand 3, student lists were coded on a 5-point rubric from incomplete to beyond complete. Students with incomplete answers did not correctly describe what and when they had to make observations to test predictions and were not highly represented. Students with mostly-complete lists missed a key detail that did not match predictions (e.g. when or what they had to observe). Students with complete to beyond complete correctly matched their observations to the predictions and in some cases also went further to suggest they test the predictions with observations. Most students were at complete to beyond complete, suggesting they had some idea of how to create appropriate observation lists. Additional instruction and modeling by the teacher may have helped more students create complete and appropriate observation lists.

Strand 3 also looked at students' ability to justify answers. Students showed mixed results in how they justified answers. There were some instances of students moving toward more sophisticated explanations where they were able to state assumptions and key ideas they had to describe where the sun or moon would be in the sky. However, there were instances of students falling back more so on observations and personal experiences rather than connecting their answers to a larger idea regarding celestial motion. There was also a very notable reliance from three students on using what they saw at the planetarium as their sole justification for answers. This suggests that students using the authority of the planetarium as a source of facts and observations as their justification rather than thinking critically about how those facts fit into a larger picture of apparent celestial motion.

Strand 4 addressed student ideas on science as a process was studied using Likert-surveys. The responses were again heavily skewed toward strongly agree and agree suggesting that students did indeed note that science is a process and not a collection of static facts. In particular, students recognized that observations in astronomy are important with 80% of responses being strongly agree on this item. Observations were particularly emphasized as part of the purpose of the planetarium visit, suggesting that the visits were useful. Student responses on an item related to listening to each other ideas and social aspects of the scientific process were also very positive with 88% of responses being agree or strongly agree. This also suggests that students were able to recognize the important of social learning and collaboration, addressed in the project portion of the curriculum.

For strand 5, tool and language use was studied separately. Most tools were only used by one group and were reference items or items used to build their project such as a globe, the Internet, a chart of moon observations, a planisphere, a protractor, and a drafting compass. Multiple groups were noted using a compass rose to determine the direction of objects in their classroom and a ruler to build their projects. Students were not told or specifically encouraged to use any tools while they made predictions or worked on their projects. This mean they had choice and control in using whatever made sense to them. This autonomy seemed to help them more smoothly work on their projects and, again, was a positive result.

Language use during the interview was also studied for Strand 5. Some students did start adopting two astronomy terms primarily. First, four students started using “zenith” as a limiting altitude in the sky that the sun would never reach, showing it was correctly used. Seven students also used “new moon”, where they clearly used it as a lunar phase that was right next to the sun or the phase that could not be seen. The term “degrees” was used by two students in the post interviews, often with the word angle attached to it when discussing the sun’s altitude, suggesting correct usage. However, seven students referred to numbers presumably in degrees on the meridian marker, suggesting they transferred information from the planetarium. Almost no students adopted the terms “gibbous moon” or “quarter moon”. Only one student used quarter moon in passing in the post-interviews. Students were exposed more heavily in class and in the planetarium show to the terms “new moon” and “zenith”, possibly explaining why those terms were more widely adopted than the others. This suggests that students may need additional exposure to terms to adopt them.

Strand 6 again looked at student ideas on their identification with science through 4 Likert-survey items. Again the trend was skewed toward strongly agree and agree, suggesting students did view astronomy as relevant in their life to some extent. Neutral responses were more heavily represented, largely due to the item “I might like to be an astronomer when I grow up.” The students are young and likely unsure of what to do for a career yet. The neutral result suggests they have not ruled out astronomy as a career and can be taken as a positive sign.

Overall, there were examples of all six strands of informal learning seen throughout the curriculum, suggesting SMILES was an appropriate starting point for planetaria as well as similarly structured informal environments. However, there were initial changes to the framework to address the more structured nature of the planetaria and some weaknesses seen regarding the six strands. As result there were suggested changes to SMILES, resulting in a revised set of guidelines I referred to as the School-Planetarium Integrated Curriculum Approach (SPICA). Not all changes, however, are unique to planetaria. As a result some suggestions on how to more appropriately address guidelines in planetarium settings were also suggested.

Again, Principle 1 deals primarily with how to embed the field trip into the curriculum and prepare students for what they will be doing. This principle is generally unchanged because students did frequently refer back to the planetarium for their knowledge in both the Likert-survey responses and interviews. However, since students seemed to miss adopting key terms it was suggested students should be prepared for the language they will encounter on the field trip in addition to the concepts. Preparing students for the language seen is not necessarily unique to planetaria. However, without labels to support students during a show, students may need extra support to be prepared for the context. This could be mediated by providing teachers with a script or an outline of the show, highlighting key terms and their context of use. This way teachers know ahead of time how vocabulary will be used and introduce that context to the students.

Another important weakness to address in Principle 1 is that many students missed key details in their ideas of apparent celestial motion in the interviews. Students need multiple exposures to ideas in order to solidify new ideas. Additionally, students took facts gained from the planetarium and used them as a sole source of justification, relying on their authority than applying to the larger picture. We want students to trust the facts and models seen in the planetarium, but we also want them to appropriately apply that knowledge when justifying ideas. Thus an additional guideline was introduced to make sure students have a chance to collect information or data as soon as possible after the show and explicitly revisit in the classroom to help with multiple exposures and retaining key details. Focusing the use of the data in the classroom on scientific practices that apply that collected data can then help students recognize their importance in a larger picture and shift their justifications beyond blind acceptance of authority. This suggestion stems from museum education literature and is applicable across multiple types of informal settings. For planetaria specifically it may be useful to focus on practices such as explanations, argumentation, and model building that explicitly use data over an extended period of time in the classroom as students will probably only have time to collect data in the planetarium setting. I can also be useful to allow students to create their own data collections sheets to further support ownership, a part of principle 1.

Principle 2 addresses choice, control, and social learning in the museum setting. Because this is difficult to address in the planetarium setting itself, this was instead fostered in the classroom through the projects. The projects were rather successful considering that a majority of students engaged with the material on a deep level and worked well with one another. Furthermore, Likert-survey results suggest that students gave some value to listening to each others' ideas. Thus, it was suggested to change the guidelines to explicitly address these key aspects of the museum setting *in the classroom* instead when dealing with more structured environments such as planetaria. Thus several guidelines were affected by shifting them into the classroom environment when dealing with structured informal environments.

With regards to social learning more specifically, the group dynamics do become more complicated in the classroom and teachers, such as Mrs. Bishop, may feel a need to group students in such as way to maintain order. This can occasionally backfire as seen with one group working on their projects with one student pulling her partner into off-task behavior. Therefore, it is important to consider these classroom dynamics carefully. Literature suggests that students grouped by heterogeneous ability levels and given specific tasks to encourage interest and motivation (Schunk et al., 1996). A large component of this is the teacher's judgment of how his or her students work together. Thus the guidelines related to autonomous group work were changed to appropriate reflect these different classroom group dynamics that need to be addressed since students have limited social learning opportunities in the planetarium.

Finally, teacher modeling of appropriate means of learning in the museum setting is addressed in this second principle. Again, this is shifted to the classroom setting as there are limited chances for the teacher to appropriately model learning in a more structured and didactic setting. However, to more fully address how students relied on authoritative information rather than apply ideas, teachers should explicitly model how to create explanations, arguments, and models for students. Specifically teachers need to model those science practices that show students that the authority the planetarium gives their information is not sufficient in science to act as a justification. Additionally, it may be useful to help students create their own data collection sheets to encourage ownership. But to also ensure that students do not miss key details from the show, it may be more appropriate for students have structured data collection sheets to match the structured nature of the planetarium. This is also something teachers can model as well as how to share and compare data to ensure all students have the correct information.

Finally, Principle 3 deals with the physical and practical aspects of the visit and preparing students for the space itself. Overall, preparation of students of the physical space has been proven useful in planetarium settings and the method of showing students pictures before hand seemed useful. The show also explicitly designed to orient students to the space at the beginning of the show including parts of the dome and visualization. Since students referred to these visualizations, it may be useful to support them at the beginning of shows with orientation to specialized equipment and visualizations used in the space.

There were also some possible structural issues with the show that should also be addressed in principle 3. Namely students showed more trouble grasping the "big ideas" related to the moon. This is possibly due to the moon topics being addressed in the second half of the show without a clear shifting point to alert students to the change in content. As a result, it may be desirable to either limit the show to a single topic or at least create some kind of break between topics through an intermission or specific agenda to help students recognize the shift in topic.

6.4. Limitations and Future Work

6.4.1. Exploratory Nature of Study

One major limitation of this work is that it was exploratory and as a result the curriculum itself was not fully piloted before implementation. It was tested with small groups of students, but never with a full classroom of students. As a result, there were notable issues in what students learned. These problems did intermingle with some of those associated with the SMILES framework, meaning there may have been some further implications that were missed. Furthermore, the exploratory nature of the program limited the study to a single class of students. Further studies should be conducted with more classes over a more diverse group of students, ability levels, and age groups.

6.4.2. Lack of Explicit Study on Social Issues

The language and tools strand (strand 5) does also emphasizes the social aspects learning using language and tools and not their use by themselves. This dissertation focused more on the direct observables of language use and tools, largely ignoring the more social dynamics between students. Social issues and interactions were noted in the study of other strands, but not exclusively. These did seem to play an important role in some student's engagement and learning and should be studied more closely to find other implications.

6.4.3. Interview Data on Justification

This was one of the first times that I had ever interviewed students. Though I did have a protocol, it focused more on the content. As a result I was able to get a consistent set of answers from students regarding their ideas about the sun and moon. On the other hand, students were asked more sporadically to justify their answers, meaning it was hard to compare student answers across interviews in the most effective way. The inconsistent nature of the asking the questions came partially from my inexperience and forgetting to always ask students these questions and partially from wanting to avoid wearing the kids out too much during the interview.

Additionally, the interview setting was meant to be more conversational to help keep students comfortable in answering the questions. As a result, students may not have justified their answers in the same way they might have in a more formal settings. Scientists will often imply connections between ideas if they are speaking with peers or people they expect to have similarly strong background knowledge. The students may have treated this setting similarly.

As a result of these factors, the interview setting was not the ideal form of data collection for studying student justification and reasoning skills. It should be studied in a more formal way such as handwritten answers from students similar to those found in McNeill and Krajcik (2007) or through multiple choice items as seen in Gotwals and Songer (2010). This would make a stronger and more consistent form of assessment for this strand.

6.4.4. Planetarium Setting

This dissertation used one of the more common topic areas that planetaria address, apparent celestial motion. However, planetaria are able to address a variety of topics including stellar life cycle, causes of the seasons and lunar phases, apparent and actual planetary motion, to name a few. Additional work on other topics may result in new insights into how the SMILES framework can appropriately apply to planetarium.

The curriculum and planetarium show was designed specifically to address the kind of show that any planetarium could do. There are two types of planetaria still in wide use today.

The first is “opto-mechanical” systems that are able to offer only an Earth-based perspective of the night sky. The second are digital planetaria that allow you to venture above the Earth and get a bird’s eye view of the solar system and fly through space. Furthermore, they can offer immersive experiences outside of astronomy topics, such as show a visitor what it is like below the ocean’s surface. Since opto-mechanical systems are not capable of this and are still commonly used, the more sophisticated visual displays of digital planetaria were not studied explicitly. As a result, similar work to this dissertation may need to be done to address digital planetaria specifically as they are becoming more popular and offer a wider array of capabilities.

The framework and this entire dissertation were also tested using a small planetarium in a local Natural History museum. This planetarium seats only up to 40 students and it was relatively easy to modify the show to the needs of this particular study. This planetarium also has a history of customizing shows for school groups to best accommodate each curriculum. However, planetaria of different sizes and staffing choice may not be able to easily change their show to match the curriculum to the same extent as this study. Thus SMILES and SPICA should be tested with planetaria that have different staffing structures and sizes.

6.4.5. Other Implications

The revisions to SMILES that resulted in SPICA are purely suggestions that resulted from what was seen in this dissertation. The recommended changes and additions to the guidelines to be used with the planetarium were more lessons learned and should be tested again by using the framework to redesign the curriculum used here or one an entirely new content area in astronomy.

This work also focused specifically on planetaria as they are very popular for field trips and can stand alone outside of other museum exhibits. However, there are other structured informal learning environments that are similar to planetaria such as live presentations and performances at the museums, IMAX movies, reenactments, role-playing, etc. Thus, the results from this dissertation could have potential applications in these fields. SPICA should be tested further not only in planetaria, but also with these other didactic informal environments.

Additionally, most of the revisions made addressed necessary changes regarding the unique aspects of structured planetarium environments. However, it is possible that some of the revised guidelines could be applicable to more traditional free-choice museum settings as well. For instance, other work has already shown that allowing students a method of collecting and annotating data at the museum is beneficial. Language and vocabulary use should also be supported across any setting. Additionally, some modern museums do still adhere to more didactic and authoritative exhibit design. Thus students could potentially project an inappropriate sense of authority in other informal settings as well, not just the planetarium. This is why further suggestions were added that addressed the planetarium more specifically. However, some aspects of the revised SMILES framework could be tested further in any informal setting to perhaps make a more refined and comprehensive framework for integrating learning across any informal setting rather than separating out the more and less structured informal learning environments.

APPENDICES

Appendix A – Curriculum

A.1. Day-By-Day Summary of Curriculum

DAY (~1 hr/day)	CONTENT	PURPOSE
Day 1- Introduction	• Introduce the unit and that students will be going on a planetarium visit and they will get to do a small project with a partner • Give them the driving question (How can we use the sun and moon to tell time?) on a large piece of paper and post it somewhere in the classroom to remind them. • Ask students about objects in the sky they know about (planes, sun, moon, stars, planets, etc.). Ask them how far away are they from the ground and how they know. • Ask them which of those astronomical objects appear to move. Ask about the moon's shapes. Ask them if they've noticed any patterns yet in their moon journal • Tell them we are going to observe the objects in the sky, make predictions, and test predictions. Then use our own observations to try and figure out ways of telling time using the sun/moon. • Introduce the idea of the sky as a dome shape with a circle that we stand on with a half-sphere over top using a globe shaped flask	• Introduction of the unit and what they should expect • Helps students activate prior knowledge related to celestial objects.
Day 2 – Coordinate Introduction, Azimuth	• Introduce concept of altitude (apparent height in sky) and azimuth (directions) • Initiate discussion by asking students what directions they know and if they know which way is which. • Prepared signs will be used with the words "North", "South", "East", and "West". Students will help by taping them to the wall in the proper direction. • We will then have a discussion on the ordinal directions (NE, SE, NW, SW) in a similar fashion to the cardinal directions.	• Further activated prior knowledge, specifically something like will likely already had instruction on. • Describing positions of objects in the sky is necessary for describing changes.

	• **HANDOUT 1:** We will go outside with the signs for each cardinal and ordinal direction. Students will work in pairs and write down the direction of various objects in the schoolyard. (Backup-do this in the classroom) • If we are outside, ask students to figure out which direction the sun is in. We'll do this by asking students to point at the sun without looking at it. Their partner will then write down the direction.	
Day 3 – Coordinate Introduction, Altitude	• Students will be introduced to the concept of altitude. Start by describing the concepts of horizon and zenith. • Altitude/height will be described as how high something *appears* as compared to the horizon. • We will all point together at 'low' altitude, medium low, medium, medium high, and high altitude. We will move our arms with each other. • **HANDOUT 2, PAGE 1:** Students will go outside and record the positions of the sun and moon. They will do with this is a globe cut out image from "Find the Constellations" from H.A. Rey.	• Introduces the second component of the coordinate system that is necessary to describe positions. • Pointing introduces KLTs that will also be used in the planetarium show.
Day 4 – Predictions	• **HANDOUT 2:** Students will work in pairs to make predictions of where the sun and the moon will be at various times of the day • Students will also make predictions of where the sun will rise, set, and be highest on the first day of, summer, spring, and fall (assuming we are in the winter) • Students will also make predictions of what the moon will look like for the next month	• This will help students feel comfortable with the coordinates and positions of objects in the sky. • They will also make predictions, which will be used as a means of helping students understand the purpose of the planetarium visit.
Day 5 – Study Design	• Discussion of students' predictions from the day before • Students will tell the teacher what they did before and what they would need to do to test predictions • Discussion will lead them toward the idea of testing their predictions to see if they are correct or if their ideas (hypotheses) need to be revised. Emphasize that scientists also make incorrect predictions and that's why we need to do observations • In small groups and then together students will make a list of observations they need to	• Introduces the specific purpose of the planetarium, integrating in the curriculum of how the sun and moon move across the sky. • Students have some ownership because they help plan the observations they need to make.

	make • Students will then split back up into their groups and discuss how feasible it is to make all these predictions. • Introduce what a planetarium is, and how it can help them test their predictions in a matter of one field trip. The planetarium will recreate the sky at all these different times to allow them to test their predictions.	
Day 6 – Field Trip Prep	• Show students pictures of the actual planetarium. • Explain to students that while they are in there, it will be dark and they might not be able to write information down, so they should try their best to remember what they saw and they will have a chance to re-record the answers to their predictions immediately after	• This is to help reduce novelty of going to the planetarium • It will also help them prepare for the types of information they will record and how they should try and remember.
Day 7 – Planetarium Visit	• Planetarium visit. Show will include a few minutes of introduction, reminder of directions, and altitude show how the sun will move through the sun for the entire day. Kinesthetic learning techniques will be used so they can follow it with their arms. Have them move their arms as it moves throughout the day. • This will be repeated for the summer, winter, and spring • Then we will move to the moon, showing what it looks like one day, moving onto a few days later and so on until a 28 day cycle has been shown. For each phase, stop it at the meridian and ask students about what time of day it is based on where the sun is. Ask them to describe the pattern. • For the last 10-15 minutes, give students a standard star talk with constellations or allow time for questions if there are any. • Immediately after, give students a chance to record the information they saw in there by writing it down or recording on copies of their prediction worksheet in different colors.	• Gives students the chance to make their own observations and test their predictions. • End of the show is to counter fatigue with content • Students regroup afterwards to have social interactions with peers related to content.
Day 8-9 – Planetarium debrief and support activities	• Discussion of prediction and how they were the same or different. Were the students right or did they learn something new? Have them cross out their original predictions and put in the correct one on a copied sheet of their paper • Discuss with students what they saw at the	• This is to help support them in ideas of how the sun and moon can be used in different ways to tell time. This may be a difficult topic for them to grasp otherwise.

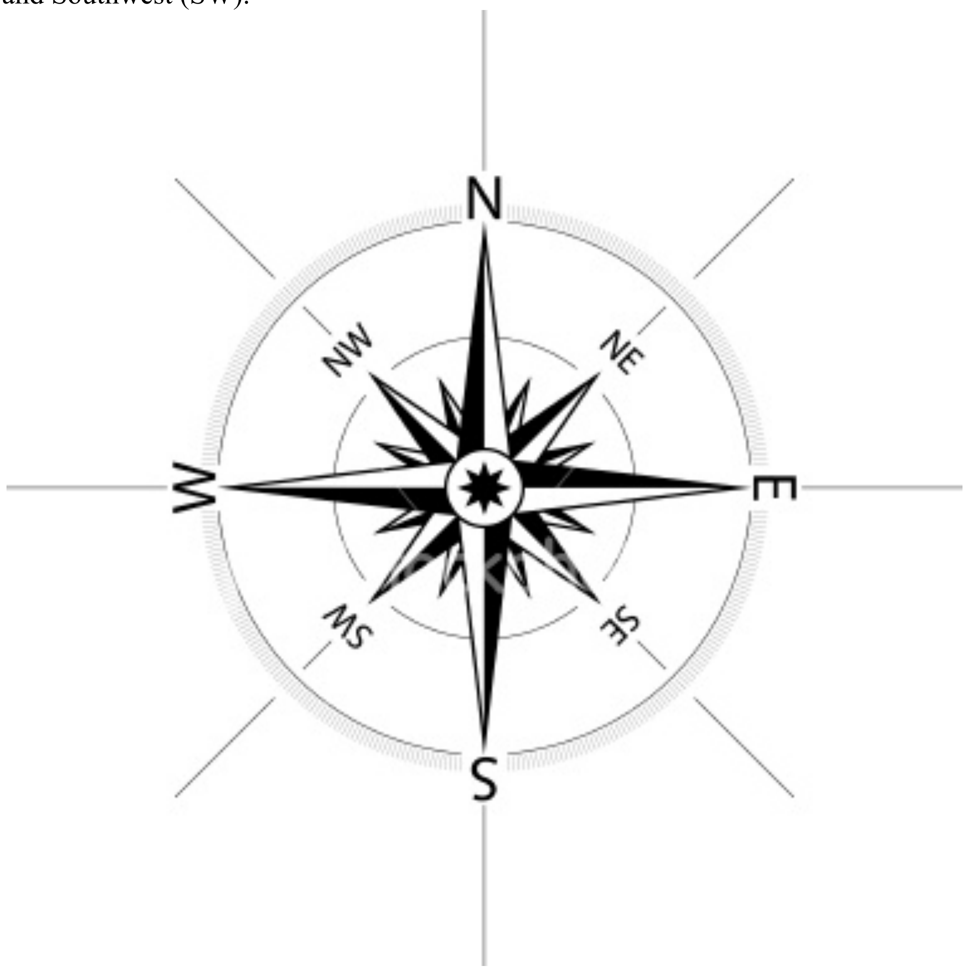
	planetarium. Remind them of their driving question and see if anyone has any initial ideas • **HANDOUT 3:** Give them activities where they need to rank the times of day and year seen based on the location of the sun and moon. Set a particular one out first and ask the students to predict which picture represents the sky each day from there on out, month, etc. For each group, have them start with a different starting point.	
Day 10-13 – Project	• Tell students they will have 3-4 days to design and (possibly) build something that uses the sun and moon to tell time • Give them a chance to star brainstorming, give them ideas if they get stuck • Allow them to either create a prototype or draw a design of their project. They can build things like sundials, make calendars, clocks, etc.	• This allows students to apply their new knowledge to a practical application that could be used in everyday life
Day 14-15	• Presentations of projects to the class	

A.2. Handout 1 – Pre-Activity – Directions

NAME:______________________________PARTNER:________________________

DIRECTIONS ACTIVITY

Today we will learn and practice describing which direction objects is in. We will describe the position of different things by using one of 8 different directions. Remember there are four cardinal directions: North (N), South (S), East (E), and West (W). There are also four ordinal directions, the ones in between the cardinal: Northeast (NE), Northwest (NW), Southeast (SE), and Southwest (SW).



Instructions:
Pick 8 big objects that do not move around the classroom or the playground and write them down in the first column of the table. (For example: Your teacher's desk, the board, the sink)
Write down which direction each of those objects are in the second column.
When you are done, find another group of students to compare what you found.

OBJECT	DIRECTION
1)	
2)	
3)	
4)	
5)	
6)	
7)	
8)	

A.3. Handout 2 – Pre-Activity - Predictions

NAME:______________________________PARTNER:________________________

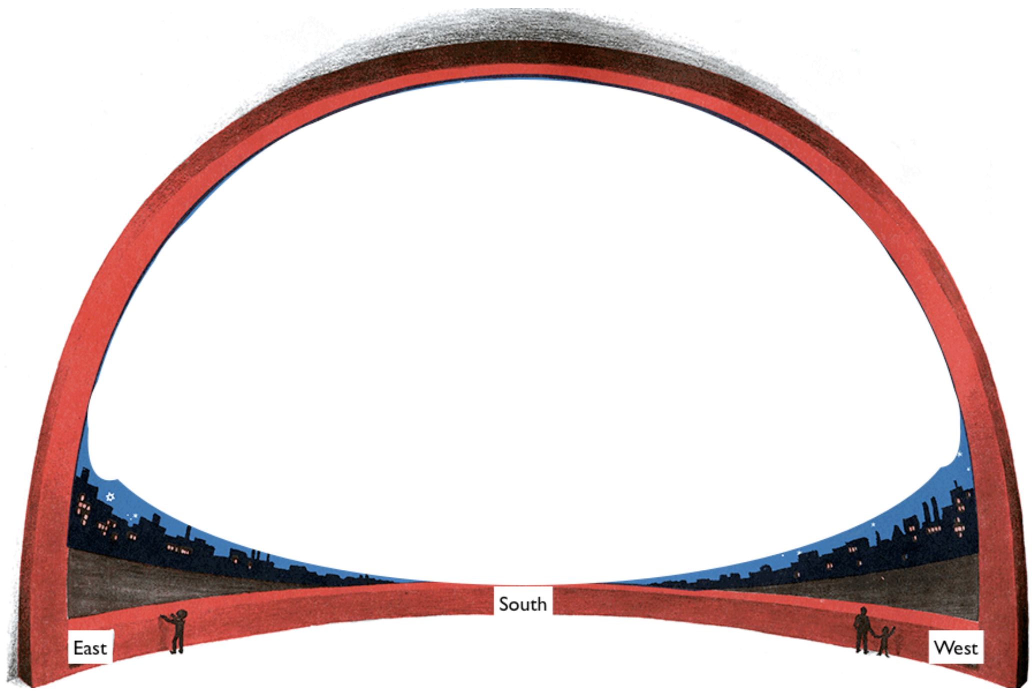
LOCATION OF SUN AND MOON IN THE SKY

Today we will put our knowledge of coordinates together and describe the position of the sun and moon in the sky. We will also make predictions on where you think they will be at different times. We will later test these predictions.

Instructions:
Find the sun and point at it. ***DO NOT LOOK STRAIGHT AT THE SUN***. Mark on the diagram of the sky the location of the sun by drawing the sun.
Find the moon in the sky and point at it. Mark in the diagram where the moon is in relation to the sun. Make sure you note both the direction and how close the sun and moon are to the horizon.

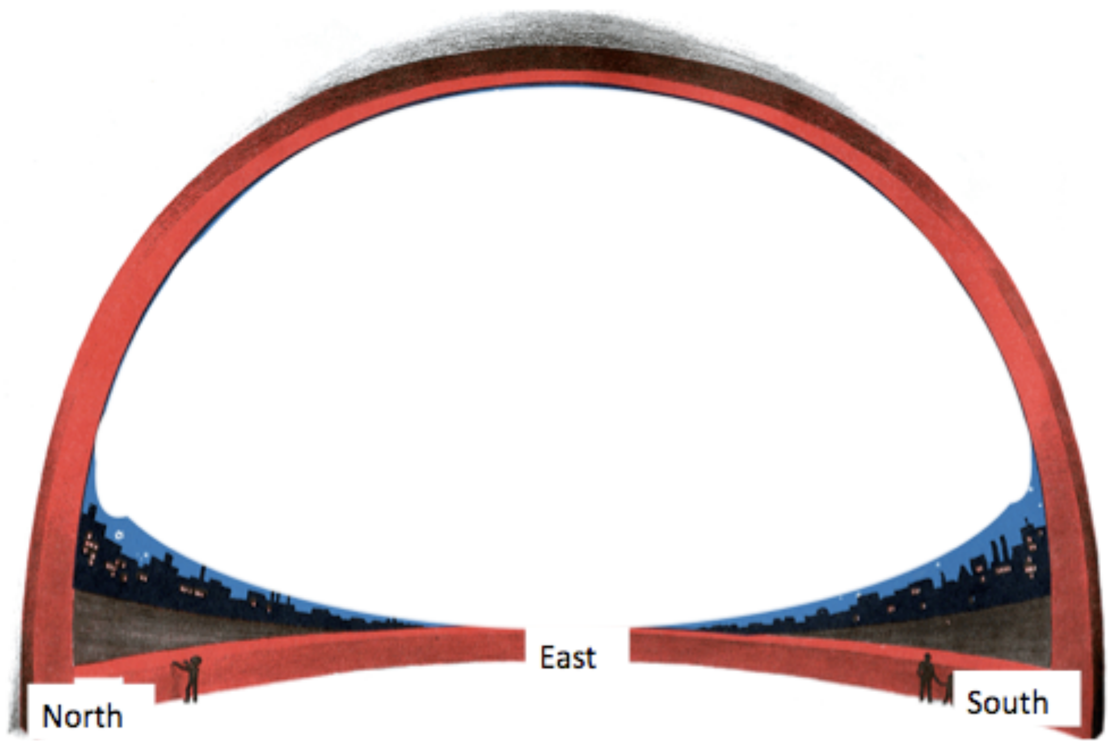
1. The diagram below is pointing ***south.*** Use it to ***predict*** where the sun will be for different times of the day. For each of the times listed below, talk to your partner and ***point*** to where you think the sun will be at each of those times. ***Mark*** where you think the sun will be each time and label each point.

   a. In a few Hours
   b. At sunset
   c. Sunrise tomorrow
   d. This time tomorrow.



2. The diagram below is pointing ***east.*** Use it to ***predict*** where the sun will rise at different times of the year. For each season, ***mark*** on the diagram where the sun will be at sunrise.

a. First Day of Summer (June 21st)
b. First Day of Fall (September 21st)
c. First Day of Winter (December 21st)
d. Friday Day of Spring (March 21st)



3. The diagram below is pointing ***south.*** Use it to ***predict*** where the sun will be when it is exactly south at different times of the year. For each season, ***mark*** on the diagram how high the sun will be when it is exactly south.

a. First Day of Summer (June 21st)
b. First Day of Fall (September 21st)
c. First day of Winter (December 21st)
d. First day of Spring (March 21st)

4. ***Predict*** how the moon will look at different times of the month.

Time of the Month	**Draw what the Moon will look like**
Today	
One week from now	
Two weeks from now	
Three weeks from now	
Four weeks from now	

A.4. Planetarium Script

Introduction:
Start the planetarium at two days before their predictions were done, at night.
Hey Everyone! Welcome to the Exhibit Museum's planetarium. I understand that you have recently made some predictions about where the sun and moon are in the sky and you came here to check those predictions. Is that right?
Explain that the planetarium can show the night and day sky for any day or time, by the operator running everything from a computer.
Explain we can show things happening very quickly, which allows us to test all the predictions they made.

Orient toward North:
First, let's orient ourselves in here. Point to where you think North is.
I see all of you are pointing in different directions. It's hard to tell sometimes which way is which, so I will just tell you now. North is this direction (point north***)***. I know this because I found these constellations, known as the big dipper (point at the big dipper). If I use these two stars, they point toward the North Star, which is always north. So, everyone stand up and face North. Not turn so you are facing east, south, west, and north again. Very good, you all know the directions in the planetarium. For now, I will turn on these labels that will help us. Notice that we also have NE, SE, SW, and NW. It's okay to sit down now.

Motion of the Sun:
I'm going to speed up the time so we can see what the sun does over the next few days. I've started this to a few days before the day that you made your predictions. I will let it go and stop at the point where you recorded the position of the sun and moon. Until then, wait for the sun to come up. When you see it point at it and follow it with your arms. Does the sun appear to move in the sky during the day?"
Let the planetarium go through at a speed of about 30 minutes/second. Let the kids follow the sun with their arms. Stop at the date and time they made their initial observations and recordings.
Does anyone remember seeing the sun and moon at this position a few days ago? Now let's test your predictions. I'm going to let the sun move across the sky as it would and stop it at each of the points you made predictions. Try and remember where it was so you can record this later..
Do this for each of the recording from the first part of the prediction handout. Slow down during the night time. When it's at noon, ask them to count how high it is using the meridian marker. At sunset, put a marker down there for where the sun set with the date. Perhaps make sunrise and sunset marker glow in the dark, but with different colors.
Did the sun go through the highest point (zenith)? Does anyone know where the sun is? What makes it night time right now?
It's almost sunrise. Where do we predict it's going to rise? ***Let the kids answer, if they say just East, ask if it's going to be perfectly east.***
Where did rise? Put a marker at that point some how to illustrate where it rose that day. Make sure the date is labeled on that marker somehow.
Ask them to show me how the sun moved across the sky, make sure they make arcs across the sky
Apparent Motion of the Sun in the Summer:

Explain that we are going to now pretend that it is June 21st, the first day of summer. We are going to 'jump to that time'.
Jump to about an hour before sunrise on June 21st.
Tell them it's right before sunrise. "Where do you predict the sun is going to appear to rise?" Repeat various answers from kids. And say "Let's see, shall we?"
Let the sun rise. "Did it rise in the same place as before?" Place marker with date at that position for sun rise.
"How high up do you predict it will get?"Let the sun continue to move. Let it stop at noon, ask them to count how high the sun is then, make sure everyone points at it. "Is it higher or lower on the first day of summer than before?"
"Where do you predict the sun will set?" Move the planetarium ahead to sunset. Place a marker there.

Apparent Motion of the Sun in Fall and Winter:

Repeat summer, but with September 21st, and again for December 21st, March 21st
What are you noticing about how the sun appears to move during the different seasons?
Have them show the different arcs for Summer and Winter
Have the kids them point to where the sun rose in summer and winter, moving their bodies to do this. Then have them point to where the sun at noon in winter, spring, summer, and back again. Ask them if they think their predictions are changing from before.

Apparent Motion of the Moon:

Put planetarium back to beginning date with predictions. So we've been looking at the sun this entire time. But you all made predictions about where the moon was going to be as well. I've moved us back to a couple day you recorded the sun and moon again. Let's watch what the moon does.
Move the planetarium in daily motion again, let the moon rise and set and have them follow it with their arms. Stop where they made their first observation again.
Does anyone remember recording this? Were any of you shocked when you saw the moon up during the day? We are now going to move the sky very quickly and stop the moon every few days so you can check your predictions.
Move the moon with daily motion, at about 45 minutes/s, Stop the moon every three days right on the meridian. Every time you do this, ask the kids if the moon looks different. Also ask them what time of day it is (morning, afternoon, evening, night, etc., not specifically number times). Do this until a full 28 day cycle is done.
What do you notice about the moon? Any patterns?

Stars Tonight Show

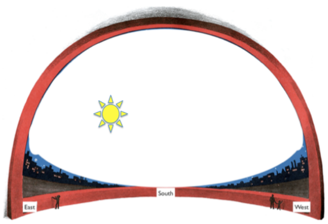
Give a standard star talk.

Do you know any constellations? Which ones? It's okay to just yell them out in this case.
Wow you guys know a lot of different constellations! Well some of those you will be able to see tonight, but not quite all of them. Let's start with my favorite, the "Big Dipper". The Big Dipper is my favorite because it can help me find the North Star and other constellations.
Point out the Big Dipper, pointer stars, the north star, Cassiopeia, Orion, Taurus (turn on pictures as I go), Aires, and whatever else will be up that night.
Let them ask questions. Thank them for coming.

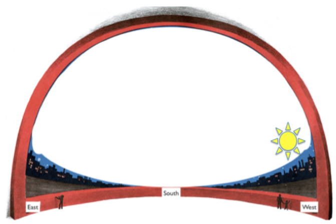
A.5. Handout 3 – Post- Activity – Ranking

NAME:________________ PARTNER'S NAME:_________________________

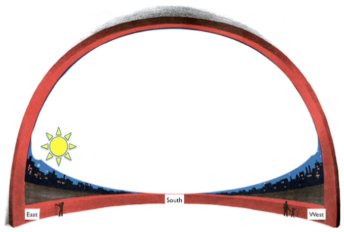
PART 1: Below shows the sun at different times of day, looking toward the south.



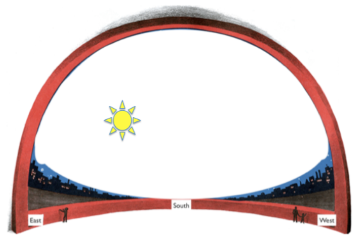
A)



B)



C)



D)

Rank the pictures based on the **time of day,** starting with the **earliest**:

1) ___________ **2)** ___________ **3)** ___________**4)** ___________

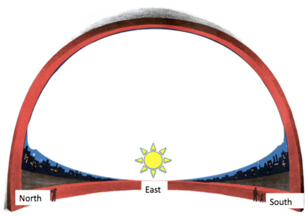
Rank the pictures based on the length of shadow the sun would cast, starting with the shortest.

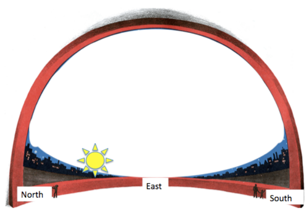
1) ___________ **2)** ___________ **3)** ___________**4)** ___________

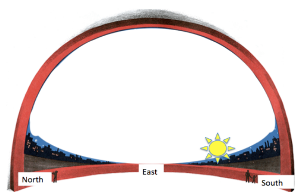
For each of the pictures, which direction would the shadow be pointing?

A)___________ **B)**___________ **C)** ___________**D)** ___________

PART 2: Below shows the sun's position at sunrise at different times of the year use it to answer the following questions

A) 

B) 

C) 

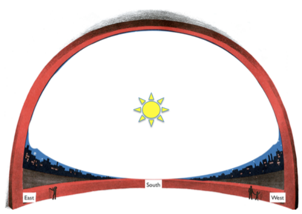
Which picture shows where the sun will rise best for each of the following seasons?

WINTER: ________ SUMMER: _________SPRING:________FALL:_________

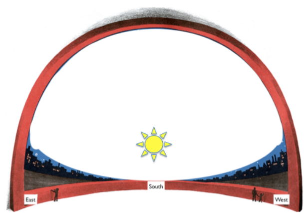
Starting with first day of Summer, rank the pictures based on when we would see the sun rise in that position. You may use a picture more than once.

1) ______________________
2) ______________________
3) ______________________
4) ______________________

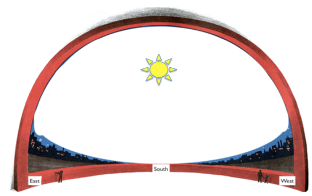
PART 3 Below use the pictures: of the sun's altitude when it is due south. Use them to answer the following questions.



A)



B)



C)

Which picture shows the altitude for the first day of each season?
WINTER: ___________ SUMMER:__________ SPRING:___________ FALL:__________

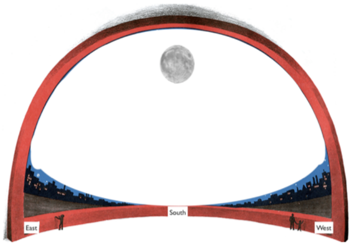
Rank the pictures according to how long of a day we would have based on the altitude of the sun when it's due south, starting with the longest day.

1) _________________ 2) ________________ 3) _________________

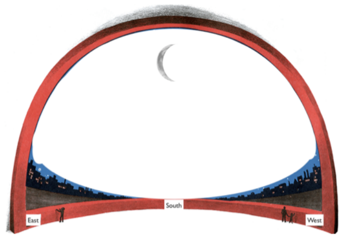
Rank the pictures according to the length of shadow the sun would cast when it is due south on that day, starting with the longest shadow.

1)_________________ 2) ________________ 3) _________________

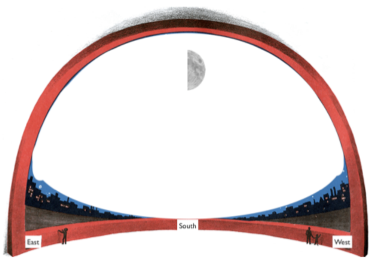
PART 4: Below shows several pictures of the moon when it is exactly south. Use them to answer the following questions:



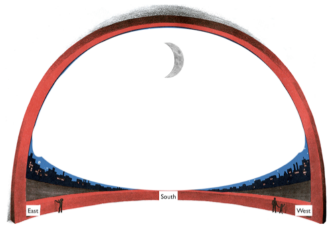
A)



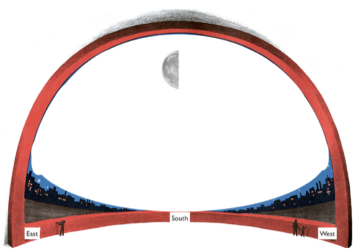
B)



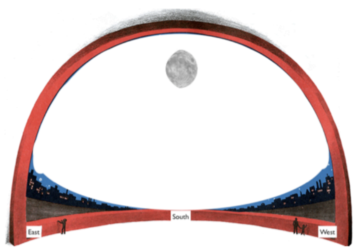
C)



D)



E)



F)

Rank the pictures, starting with the first phase after New Moon, in the order we'd see them
1)_________2)________3)__________4)_________5)_________6)_________

Rank the pictures according to what time of day it is, starting with the earliest.
1)_________2)________3)__________4)_________5)_________6)________

Appendix B – Instruments

B.1. Likert-Scale Post-Survey

(This survey includes some minor formatting changes from the original given to students)

	Strongly Agree ☺	**Agree**	**Neither Agree nor Disagree** 😐	**Disagree**	**Strongly Disagree** ☹
I think astronomy is **fun**					
It is **okay** if scientists **change their ideas** about astronomy					
I **can understand** astronomy					
I would like to **learn more about** astronomy					
It is **important** to make **observations** in science					
I might **like to be** an astronomer when I grow up					
The planetarium visit was **interesting**					
Scientists **never finish** studying astronomy					
Only astronomers use astronomical information					
I **enjoyed** the planetarium visit					
It is **useful** to listen to new ideas in science even if everyone does not agree					
Only astronomers can understand astronomy					

Have you ever been to a planetarium before this field trip? Circle your answer.
YES NO

What was your favorite part of this unit? Why?

What was your least favorite part of this unit? Why?

B.2. Interview Protocol

What is your name? ___________________________________. Hi.
My name is Shannon and I am from the University of Michigan. I am working on a project on improving astronomy learning with planetarium field trips. I'm going to ask you questions about the sun and the moon in the sky and have you make some predictions. This isn't part of your grade, I won't tell your teacher what you answered. This is to tell me what you already know before you start learning astronomy so it is important that you answer the best you can. Sound good? Do you mind if I record what we are saying to refer back to it later?
For each prediction question, if they do not try to justify their answer, ask them to tell you why made that prediction.

Motion of the Sun Today:

1) Does the sun appear to move in the sky during the day?
    a. *If yes*, can you describe how it moves throughout the day? How do you know this?
    b. *If no,* Where does it go at night?
2) How high does the sun appear to get? Highest point? – *If they ask what is meant by how high, ask if the sun looks like it's directly above their head, close to the ground or somewhere in between.*
3) Can you describe where the sun is in the sky right now?
    a. Can you describe where the sun was when it rose this morning?
    b. Can you predict where the sun will be at lunchtime today? Why do you say that?
    c. Can you predict where the sun will be at the end of school today? Can you tell me why?
    d. Can you predict where the sun will be when it sets? Why do you think it's going to be there?

Motion of the Sun in Summer:

1) Now pretend we are outside during the summertime. What do you like to do during the summer?
2) How high does the sun appear to get? How do you know?
3) Can you predict where the sun will rise? Why do you think that?
4) Can you predict where it will be a little later in the morning? Why?
5) Can you predict where it will be at lunchtime? How do you know?
6) What about when it sets? Why do you say that?
7) Is there any difference between where the sun is during the winter and the summer?

Motion of the Sun in *Autumn (Okay to skip if they say it will always be the same all year round):*

1) Now pretend we are outside during the falltime. What do you like to do during the fall?
2) How high does the sun appear to get? How do you know?
3) Can you predict where the sun will rise? Why do you think that?
4) Can you predict where it will be a little later in the morning? Why?
5) Can you predict where it will be at lunchtime? How do you know?
6) What about when it sets? Why do you say that?
7) Is there any difference between where the sun is during the winter and the autumn?

Changes in the Moon:

1) Does the moon appear move at all in the sky? How do you know?
    a. ***If yes,*** Can you describe how it moves? How do you know this?
    b. ***If no,*** Where is the moon when we can't see it?
2) Can you ever see the moon during the day?
3) Does the moon always set when the sun comes up?
4) Does the moon ever appear change shape? ***If yes,*** describe how the moon changes shape.
    a. How often does it change?
    b. Is there a pattern to how the moon changes? If so, what is that pattern?
    c. How many days does it take to repeat that pattern?

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