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Using a planetarium to support pre-service elementary teachers' development of NGSS-aligned science teaching.

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USING A PLANETARIUM TO SUPPORT PRE-SERVICE ELEMENTARY TEACHERS' DEVELOPMENT OF NGSS-ALIGNED SCIENCE TEACHING

By

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ABSTRACT

USING A PLANETARIUM TO SUPPORT PRE-SERVICE ELEMENTARY TEACHERS' DEVELOPMENT OF NGSS-ALIGNED SCIENCE TEACHING

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This dissertation is a case study of five elementary pre-service teachers within a science methods course who attended a planetarium-enriched experience. The experience was designed and taught by an instructor with both experience and education in astronomy and with K-12 students. The focus of the planetarium experience was to teach the science content these PSTs will have to teach to their future elementary students and teach how to teach science in an NGSS-aligned way, by incorporating the Science and Engineering Practices and Crosscutting Concepts.

This is a qualitative case study that relied on interviews, open-response surveys, and video prompt responses to collect the pre-service teacher perceptions of science instruction and the impacts of the planetarium-enriched experience on their learning of science, and future science instruction. The pre-service teachers were also observed in their methods class to help build the case for each interviewed student. There existed 8 remaining students who participated in all of the methods of this study but did not choose to be interviewed, but were aggregated to inform the five interviewed cases. All data was analyzed through line-by-line open coding of transcripts and surveys.

The results show that the pre-service teachers felt the planetarium helped them learn science through visual modeling and physical modeling. Many of the cases described having little science background. They felt that they benefitted from the multiple representations of the Sun-Earth-Moon system for their own learning and for their learning to be future science teachers. The pre-service teachers also described the benefit of the planetarium instructor because of their experience in space science and K-12 science education.

The planetarium-enriched experience helped these five elementary pre-service teachers in all three contexts of learning (physical, sociocultural, and personal). This may have led to their perceptions that the planetarium helped them learn the material for themselves, and serve as a model for NGSS-aligned instruction to look back on and attempt for themselves in their own classroom. The planetarium experience provided a tangible example of NGSS-aligned instruction and all cases described the benefit of having the experience as part of their methods course.

DEDICATION

This dissertation is dedicated to my husband, Will, for his unwavering support. Your patience, encouragement, and belief in me throughout this process have been a cornerstone of my success. Thank you for motivating me throughout this process, for enduring all of the acronyms I threw at you, and for reminding me daily that we are a team. I love you now and forever.

I also dedicate this dissertation to my parents. Dad, thank you for taking me out to see that meteor shower at 2 in the morning all those years ago. You opened my world to the stars and for that I am thankful. Mom, thank you for always being there to listen to me, support me, and encourage me to follow my dreams. You have always been my cheerleader and I would not be where I am today without you.

Finally, I dedicate this dissertation to Dr. Steve Nettleton, in loving memory. You were like another father to me for so many years, and you gave such great advice throughout my dissertation process. I wish you could be here now to see me through the end of it, but I am eternally grateful for your guidance.

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CHAPTER 1: BACKGROUND

There is an ongoing need for science education to be more robust and inquiry-based (Dye et al, 2013; Lewis & Lu, 2017). The Benchmarks for Science Literacy, published by the American Association for the Advancement of Science in 1993, articulated the first set of national reform-oriented guidelines for teaching science to students (AAAS, 1993). These guidelines included ways to effectively teach science, specifically “an emphasis helping students develop (1) familiarity with a discipline’s concepts, theories and models; (2) an understanding of how knowledge is generated and justified; and (3) an ability to use these understandings to engage in new inquiry” (NRC, 2005. p. 398). The need for inquiry-based, student-centric instruction has been researched and included in national science guidelines since 1993 (NRC, 2011). This approach to instruction has shown an increase in understandings and the transfer of knowledge (DeBoer, 1991) to new contexts when compared to memorization-based instruction alone (Bransford, Brown & Cocking, 2000).

The use of inquiry instruction and hands-on learning continues to align with current national goals for teaching science to students. The Next Generation Science Standards (NGSS) transformed the former standards of inquiry learning into three dimensions of science learning based on The Framework for K-12 Science Education (NRC, 2011). These include Disciplinary Core Ideas, Science and Engineering Practices (SEPs), and Crosscutting Concepts (CCCs) that respectively emphasize using phenomena to drive sense-making, demonstrating how scientists do science, and showing how all science is connected. All three dimensions are combined to create standards presented as performance expectations that require science instruction to be phenomenon-based, be student-driven, and include active learning. The integration of Disciplinary Core Ideas, SEPs, and CCCs is known as three-dimensional learning (NRC, 2014). NGSS has expanded on the idea of inquiry instruction to develop the SEPs to articulate for students how inquiry uses the eight scientific and engineering practices and includes them in the standards. These practices include, for example, students conducting investigations and making sense of phenomena in the real world by developing and deploying student-created models (Schwarz, et al., 2017).

NGSS also requires students to be able to complete performance expectations as a form of assessment for completing the standards (NGSS Lead States, 2013). These performance expectations are expressed as knowledge-in-use by asking students to perform science as a scientist does and applying practices of science and engineering to the Disciplinary Core Ideas while incorporating crosscutting concepts as a helpful sense-making mechanism (NRC, 2011). For example, an Earth and Space Science performance expectation for middle school students states, "Students who demonstrate understanding can: develop and use a model of the Earth-Sun-Moon system to describe cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons" (NGSS Lead States, 2013). This standard requires students to demonstrate an understanding of astronomy by developing and deploying a model as a scientist would in order to explain natural phenomenon. In this example, NGSS requires students to not only learn astronomy but also to demonstrate astronomical understanding through the use of the practice of modeling. Additionally, students make sense of phenomena using the crosscutting concept of patterns which is a relevant way of thinking across the sciences. The standards are scaffolded throughout the K-12 curriculum, building on prior learnings and concepts to create storylines that seamlessly incorporate all three dimensions.

The use of phenomenon-driven science instruction is often utilized in informal science educational environments, with the primary goal in these institutions to create hands-on learning experiences driven by real-world phenomena in educationally and technologically innovative ways (Falk & Dierking, 2000; NRC, 2009). Planetariums are uniquely situated in this context of educational advancement due to the nature of complex technology to actualize and model large astrophysical and Earth science concepts (Slater, 2017). Research suggests these phenomenon-driven tools may help students and teachers in conceptualizing the nature of science along with science content knowledge (Adams, et al., 2014; Jung & Tonso, 2006).

Study Significance

The Framework for K-12 Science established standards in K-12 education (NRC, 2011) upon which NGSS was based. This framework stated the following as the main goals in science formal education:

> By the end of 12th grade all students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology (p. 1).

These goals can be daunting to teachers, especially those early in their careers. There is a significant body of literature that describes many young teachers, especially elementary school teachers, who are not always comfortable nor confident in their abilities to teach science (e.g. Gerde, et al., 2018; Menon & Sadler, 2016; Mosely, et al., 2016). These beginning teachers often have problems finding resources, such as classroom materials and lessons, to support the newer theories of science learning that are more inquiry-based (Gerde, et al., 2018). Appropriate teacher preparation programs are needed to support the development of teachers who can meet these reform-oriented goals of engaging students in their learning by making the content relevant to their lives and interests.

Beginning elementary teachers experience many issues when teaching science in elementary classrooms, but one of the more challenging aspects includes seamlessly integrating all three dimensions using a phenomenon-driven and sense-making lens in their science instruction (de los Santos, 2017). This study will explore a particular phenomenon-driven lesson experience—using a planetarium—to support pre-service elementary teachers' development of their own abilities to teach their future students in a similar way. The planetarium-based lesson experience does a deep dive into two Disciplinary Core Ideas, The Universe and its Stars and Earth and the Solar System. The experience focuses on the apparent motion of the Sun and Moon over different lengths of time (day, month, year) from an Earth-based perspective and includes modeling to explain this motion from a space-based perspective. These Disciplinary Core Ideas require the CCC of patterns to observe the pattern of apparent motion and the SEP of modeling to explain the apparent motion and assist in the explanation of these patterns.

Teachers, both pre-service and experienced, who engage in an informal educational program show more confidence in teaching science and are more likely to utilize reform-minded pedagogy along with integrating informal instruction into their classrooms (Dewitt & Osborne, 2007; Griffin, 2012; Kisiel, 2013; Dori & Tal, 2001). Informal environments can provide access to resources that aren't typically available to classrooms or to most people. One role of museums is to expose people to the nature of science and what scientists are doing to advance society through scientific inquiry and discovery (Faria, 2015). The purpose of informal science environments (ISE) is to engage, educate, and inspire others through visually stimulating, hands-on, and minds-on experiences (Kim, 2016; NRC 2009). ISEs provide learning environments with unique features that enhance curiosity, motivation, and interest in science.

Planetariums are an example of an ISE. Planetariums provide a unique opportunity to expose teachers to technologically and educationally advanced tools as a means to convey science content and science and engineering practices (Slater, 2017). Planetariums use dynamic visualizations that are more beneficial due to the immersive nature of a full-dome experience. Research suggests that full-dome visualizations are better at supporting student learning in spatially complex phenomena such as lunar phases from both an Earth and space-based perspective, when compared to a flat visualization such as on a TV or computer screen (Plummer, et al., 2015). The planetarium is used in this lesson experience to create full-dome visualizations of the apparent motion of the Sun and Moon over time to show the positions of the Sun as it rises and sets over the course of a day, the phases of the Moon as it rises and sets over the course of a month, and the difference in direction of Sun rise and set over the course of a year.

Study Purpose

This study will test a promising pedagogical tool for astronomy—a planetarium—to be integrated into their formal university science methods course to help pre-service elementary teachers in deepening their knowledge of the multidimensionality of NGSS to include Science and Engineering Practices (SEPs) along with Crosscutting Concepts (CCCs) in their instructional planning and facilitation. Planetariums are uniquely situated to provide a rich and immersive, in-depth learning experience in both content and pedagogy in the multidimensionality of science learning.

The importance for beginning teachers to know the science content of what they will teach is foundational, but the need for pedagogical training and a deep understanding of the curriculum is also essential to becoming effective teachers. This study will identify how teachers engaging in a deep-learning planetarium experience with multidimensionality embedded throughout and explicit attention on pedagogy alongside content impacts teachers' understanding of the multidimensional and sense-making emphasis of NGSS. This study will also analyze how the use of the planetarium for this experience impacted their learning both as a student and as a future teacher.

Research Questions

1. In what ways can a short planetarium-enriched learning experience within a science methods course shape the perceptions of pre-service teachers (PSTs) as science learners and as future teachers of science?

2. How can a short planetarium-enriched learning experience within a science methods course inform PST perspectives of science instruction aligned with the Next Generation Science Standards?

CHAPTER 2: LITERATURE REVIEW

This chapter focuses on five main parts that synthesize the existing literature related to this study. The first section is an overview of Next Generation Science Standards (NGSS) and national science instructional goals for teachers and students in terms of three-dimensional science instruction using phenomenon-based instruction and sense-making. The second section is a literature review of pre-service elementary teacher training in science, which is often limited in scope due to time constraints and thus limited in adequately training future elementary science teachers. The third section contains a further literature review of informal education, with a specific focus on informal science educational environments (ISEs), such as planetariums, and their benefits. The fourth section synthesizes how ISEs may be of benefit for supporting pre-service teacher training programs. The final section is the theoretical framework, the Conceptual Model of Learning (CML) by Falk and Dierking (2000), that underpins this study.

NGSS and Science Learning

Multidimensional Learning

Prior to the development of NGSS, there was growing frustration among many stakeholders who saw science being taught as a collection of facts instead of the inquiry approach and coherent curriculum defined in the ’90s and ’00s (AAAS, 1993). Many believed the former standards, the National Science Education Standards (1996), were published without offering adequate support or professional development to teachers.

They were viewed as prescriptions handed down to teachers, which could quickly be tossed out in favor of the traditional method of science teaching, direct transmission (Bybee, 2014). As a result, the National Research Council convened to develop a Framework for K-12 Science Education in 2011 (NRC, 2011) and the Next Generation Science Standards in 2013 (NGSS Lead States, 2013). These standards explicitly align science curriculum through learning progressions and content storylines for each grade level, as well as providing crosscutting concepts and seamlessly integrating the practices of science into the curriculum. Thus, the three integrated dimensions of science learning in the NGSS are Disciplinary Core Ideas (DCIs), Science and Engineering Practices (SEPs), and Crosscutting Concepts (CCCs) in science.

The NGSS were developed with the purpose of providing more instructional support than the 1996 standards for incorporating unifying concepts, now known as crosscutting concepts, and science and engineering practices throughout science instruction (Osbourne & Quinn, 2017). The practices of science were previously included in the standards as a separate topic for instruction, but more integration of the practices was needed to ensure how science is done was at the forefront of science instruction. This integrated approach was also intended to support teachers in providing authentic sense-making tasks for students. NGSS served as a way to integrate the practices of science and the crosscutting concepts that connect all science within the standards to ensure three-dimensional teaching (Bybee, 2014). NGSS focuses on informing teachers about the content, as well as how to connect core ideas to other areas in science and outside of science education. The focus of assessments aligned with NGSS would be based on performance expectations where students are not assessed on random, disconnected facts but instead are assessed on their performance in doing science or applying scientific knowledge in some way, be it argumentation, developing a model, etc. A feature of NGSS that has proven to be challenging for teachers is the systematic and effective incorporation of the SEPs and the CCCs (McFadden, et. al., 2024).

Phenomenon-based Instruction

Phenomena are defined as natural, observable events in the universe that we can explain or predict a solution to a real-world problem using science or engineering. NGSS recommends phenomena-first instruction to build science knowledge based on the phenomena as the context for science instruction. The purpose of using phenomenon-based instruction is to contextualize student learning around phenomena to emphasize the purpose of science—building an understanding of how and why the natural world functions the way it does. Students can use the phenomena to anchor their learning as a focus of a unit and investigate phenomena to develop their scientific understanding of the natural world.

Sense-making

NGSS has also shifted science instruction from knowing science to using science and engineering to make sense of the world or to solve real-world problems. This shift in the focus of science instruction to using scientific thinking to contextually make sense of the world is novel for most teachers. This shift in instruction is a shift from traditional science instruction where students simply know the information (i.e. memorizing diagrams facts, and vocabulary) without understanding what the information means or making sense of it. As demonstrated in Figure 1.1 sense-making is pivotal to tying the eight science and engineering practices in the trapezoids of the figure together. Sense-making is the common thread between science and engineering practices used in conjunction to make sense of the world.

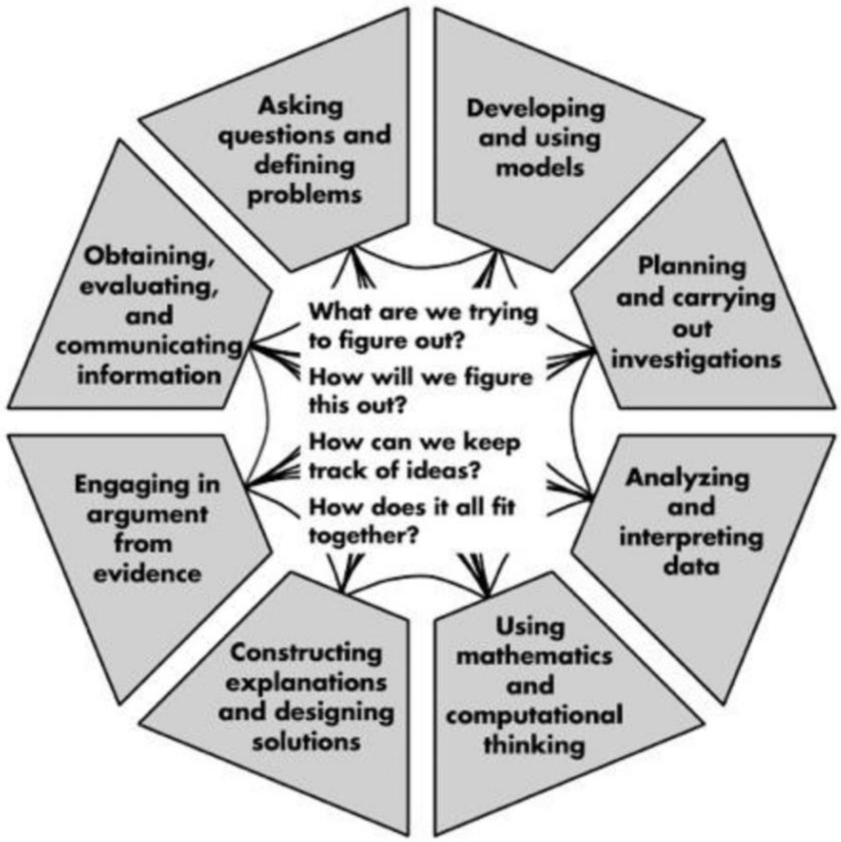

Figure 1.1. Sense-making and the Science and Engineering Practices (Schwarz, Passmore, and Reiser, 2016)

Astronomy in NGSS

NGSS has included astronomy as one of the four DCIs that progresses through the K-12 standards, using the label of Earth and Space Science (ESS) and the first of three sub-DCIs in this category for elementary science labeled as Earth's Place in the Universe (ESS1). The progression of ESS suggests introducing astronomy in first grade (but groups all K-2 standards together for school/district flexibility) by having students investigate the Sun, Moon, and stars to describe the patterns (a crosscutting concept) they make moving across the sky. Students also use those patterns to make predictions (a science and engineering practice of arguing from evidence). Grades 3-5 ESS1 standards are recommended for fifth grade and include supporting an argument that the apparent brightness of the Sun compared to other stars is due to their relative distances; creating graphical data of the changes of the shadows cast during an entire day as well as how those shadows change over the course of a year; and looking at seasonal changes of stars in our night sky. The middle school standards do not recommend a particular grade to teach ESS standards but include developing and using models to describe the cyclical patterns of the Moon, Sun, eclipses, and seasons. Standards for this DCI also recommend introducing models for gravity and describing how gravity has influenced the shape and motion of our Earth, solar system, and galaxy.

NGSS has been a powerful guideline of standards, with 19 states fully adopting them, 22 additional states creating standards based on NGSS, and 4 states planning on adopting or adapting NGSS as of 2019 (Thompson, 2019). Although the standards are not meant to be a curriculum for teaching science in K-12 classrooms, the standards do provide a useful framework that includes explicit storylines and connections between concepts and practices of science that are normally kept separate. They also provide the basics of science education for all students regardless of their future career aspirations.

Pre-Service Elementary Teacher Education in Science

Elementary teachers today face a growing number of demands for teaching science along with being able to teach all other subjects to a diverse range of students (Nowicki, et al., 2012). NGSS places increased emphasis on teaching science through exploratory, authentic experiences, but many elementary teachers may not have a sufficient science background to be effective teachers of science, which may lead them to pass their misconceptions on to their students (Atwood & Atwood, 1996; Burgoon, et al., 2011; Krall et al., 2009).

Many pre-service teachers (PSTs) may not have thorough science content knowledge and consequently may lack the confidence to teach science (Beck, Czerniak, & Lumpe, 2000; Kazempour, 2009). Studies suggest that teachers with low science content knowledge for teaching will often rely on textbooks and traditional lectures about scientific facts instead of using inquiry-based instructional strategies (Nowicki, 2012). Many PSTs have preconceptions about science instruction needing to be more teacher-centered instead of student-centered, which often results in science instruction in the form of direct transmission (Hamed, et al., 2020; King, Shumow, & Lietz, 2001). However, pre-service preparation programs exist at a critical point where they can shape and challenge PST attitudes and beliefs (Haney, Czerniak, & Lumpe, 1996; Moore, 2008). PSTs' reflection on science learning in their science methods course can counter their lived experiences of learning science themselves and cause PSTs to then apply reflective considerations to their future teaching practice (Kazempour & Sadler, 2015). Effective teachers are typically highly reflective persons who think about their own learning of content because they recognize the value of continuing to learn even as they are strengthening their practice of teaching (Zeichner & Liston, 2013).

The need for pre-service teacher training to focus on developing science content knowledge as well as how to teach science has become more prevalent since the release of NGSS. As a result, some recent pre-service educational programs created specialized science courses for PSTs that focus on developing science content knowledge to help

PSTs become more knowledgeable about the science content they will teach and to increase their confidence in teaching science (Haefner, & Zembal-Saul, 2007; Menon & Sadler, 2016; Santau, et al., 2014). Increasing PST science content knowledge could lead to more teachers being able to facilitate science discourse among their students via inquiry in the classroom (Davis, 2004; Luera, et al., 2005; Newton & Newton, 2001).

Preservice elementary teachers often have one science methods course that focuses on science content, standards, and instructional methods that align with the standards. The overwhelming amount of content included in a science methods course can be very challenging for preservice elementary teachers due to very limited time in class, science knowledge base, and lack of prior experience with adequate science instruction (Appleton, 2006). The amount of material to cover also presents a challenge to science methods class instructors to determine the most beneficial uses of course time for preparing their elementary PSTs (Santau, et al., 2014). Methods course instructors must be very critical of what content they can meaningfully include with the very restrictive time constraints presented in one methods course, which is not enough time to adequately prepare PSTs for everything that will be required of them in an elementary science class.

Informal Education

Informal education is defined as education that happens outside of the traditional classroom setting. Informal education is a broad area that can refer to very different forms of education such as after-school programs, community-based organizations' workshops, YouTube videos, summer camps, or museum programming (Rennie, 2007). This type of education is not designed for formal classroom settings, is often voluntary, and typically relies on intrinsic motivation, and free choice to explore (Falk & Dierking, 2002).

The literature often does not discern between informal educational experiences and informal environments. Many institutions may be informal in the sense of being outside of the school but are still formal in their educational experiences where students are still sitting and listening to an informal institute instructor teach one lesson to all students in one way. Informal education can span a spectrum of educational styles from complete free-choice, low-stakes, and multiple modes of learning to more structured and organized experiences (Falk & Dierking, 2002). Some informal educational environments have developed curriculum that is quintessentially both informal and formal learning. Students do not have a choice in attending a field trip and participating in the lesson but the activities they will do have some aspects of free-choice learning with the help of an informal science educational guide. For example, the guide can provide many ways to participate in a lesson such as designating an area of the museum to focus students' attention and providing a learning objective that must be explored in that part of the museum, but students have choice in which exhibits in the designated area to explore. The distinctions of the spectrum of informal learning are often blurred in most cases, with the possibility of some structured (e.g. a guide providing an overview or demonstration) and some less-structured activities (e.g. time for students to independently explore).

Informal Science Educational Environments

Informal science educational environments (ISEs) are places where science learning happens outside of the classroom but are a part of an organization typically with goals for furthering scientific knowledge and inspiring lifelong learners in science. These can be nature parks, zoos, museums, planetariums, etc. ISEs draw heavily upon the theoretical framework of John Dewey by focusing on creating authentic experiences and opportunities that may be difficult to experience within the confinements of a classroom (Kolb, 1984). And as the curriculum theorist John Dewey described, learning takes place mostly when people are engaging in the real world where learning takes place between the learner and their interaction with the environment (Dewey 1938). ISEs give schools the unique possibility of providing instruction out in the real world, with real scientific tools or models, while guided by experts in their respective fields. These informal environments give their students opportunities to visit cultural, historical, and scientific places within their community that they may be unable to experience in their home life (Greene et al. 2017).

The constructivist view of learning is that learners contextualize, and construct knowledge based on their environment and the social interactions within them. These relationships can bring out a new depth of understanding and meaning to knowledge or experiences they have outside of the classroom. Informal environments can provide access to resources that aren't typically available to classrooms or to most people. A role of museums is to expose people to the nature of science and what scientists are doing to advance society through scientific inquiry and discovery (Faria, 2015). Informal science environments (ISE) aim to engage, educate, and inspire others through visually stimulating, hands-on minds-on experiences (Kim, 2016). Science museums provide learning environments with unique features that are designed to enhance curiosity, motivation, and interest in science.

The benefits of ISEs are extensive in the literature, such as reporting that many in science-related careers credit their initial interest in STEM to informal rather than formal exposure, with museums and science centers having the biggest impact on stimulating their interest in science (Adams, et al., 2014; NSF, 1998). Several scientists noted that visiting these ISEs caused the spark that led them to want to know more and inspired them to become lifelong learners. The free choice and nonevaluative nature of these environments are often aspects that promote and nurture learning (Tran, 2007), and can be combined with other more structured experiences to support learners in processing their experiences. The hands-on experiences create opportunities to develop scientific knowledge in an impactful and lasting way. Inquiry and hands-on learning through informal educational means is a way to engage all students and provide the space and opportunities for all students and teachers to learn science (Riedinger, et al., 2010).

Planetariums as an ISE

Planetariums are a common form of an informal science educational environment with most major cities and universities housing at least one (Bishop, 1977). Planetariums are unique to other informal environments because of the technologically advanced equipment used to create a three-dimensional and immersive projection which allows for accurate depictions of astronomical phenomena by rendering visualizations stereoscopically (Price et al., 2015). Astronomy concepts are usually abstract and require cognitively complex three-dimensional thinking to accurately portray phenomena (Yu, 2005). Astronomical modeling is fundamental to learning about the celestial bodies due to the very large scale and often very long time periods for which patterns of change happen. Planetariums can alleviate these difficulties in comprehending astronomy concepts by providing 3D simulation modeling for manipulating time to observe celestial patterns and motion and bringing the large spatial scale nature of astronomical phenomena down to a more comprehensible size (Türk & Kalkan, 2015).

The unique environment of a planetarium dome offers the opportunity to make astronomical observations of daily, monthly, and yearly patterns in the sky in moments as opposed to making lengthy observations in real time (Tomlinson, 2011). This can allow students to experience and observe the scientific processes and interactions necessary to describe Earth's place in the universe (Thornburgh, 2017). Studies suggest the use of a planetarium can be effective at teaching astronomical and scientific concepts (Bishop, 1980; Palmer, 2007), and the effects of planetarium instruction are also effective for student retention of information over longer periods of time (Palmer, 2007; Thornburgh, 2017).

Planetariums are uniquely situated to support aspects of both formal and informal learning. Planetariums are often informal in environment but formal in context as students are all usually engaging in one lesson together with a planetarium educator (Slater, 2017). There are activities that some planetariums use that are also informal in educational contexts where students have choice in materials to create models or choice in which exhibit to engage with (Plummer, 2015). These activities typically take place outside of the planetarium dome and are hands-on activities or exhibits for students created by planetarium professionals with specific goals and learning objectives in mind.

Hands-on activities in planetariums are helpful for effective learning in astronomy and spatial reasoning (Rusk, 2003). Studies suggest that students who see a planetarium show about the Moon phases and experience a physical model of the Sun-Earth-Moon system had statistically significant gains over just the use of the in-dome show (Plummer, 2009; Rusk, 2003). Students who attended the planetarium show also retained information for longer periods of time (Thornburgh, 2017).

As summarized above, planetariums have promise for learning and the retention of learning for K-12 students. The planetarium offers a rich, dynamic example of how NGSS three-dimensional learning is organized around phenomena, which can support stronger elementary student learning. This study will extend the literature that focuses on K-12 student learning to analyze pre-service elementary teacher learning within a planetarium. The planetarium experience included three-dimensional learning with a focus on phenomenon-based instruction and sense-making, learning for themselves as science learners, and learning as future teachers of science.

Informal Science Learning for Teacher Education

ISEs can also help teachers develop reform-minded identities by assisting and supporting what teachers do in their classrooms. Research suggests that involving teachers in inquiry investigations as learners helps them understand what it means to be a scientist and the nature of science. This often requires teachers to engage in inquiry investigations, not through the lens of a teacher, but learning as students themselves. Teachers who participated in inquiry investigations were also more likely to include inquiry in their science instruction (Haefner & Zembal-Saul, 2004).

ISEs can help by providing teachers with examples of the relevance of science to phenomena in everyday life, hands-on activities to get students actively engaging in scientific practices, and the means to create a deep understanding of specific concepts instead of the surface-level, broad, superficial understandings of science facts that plagued science teaching in the past (Varma, 2009). ISEs can provide stepping stones for new teachers to provide a strong foundation in the nature of science and science education. Implementing ISEs in pre-service teacher programs can be mutually beneficial for new teachers and the museums in which they take place. Access to ISEs in teacher preparation programs can provide more authentic experiences with the content they will be teaching, as well as access to new resources and experts in each particular field of science to offer guidance on the content (Anderson, 2006). Pre-service teachers who regularly had classes in an informal setting showed gains in self-efficacy and self-confidence in teaching science (Avraamidou, 2014).

Riedinger, Marbach-Ad, McGinnis, Hestness, and Pease (2010) studied, through Project Nexus, a group of pre-service teachers in an elementary science methods course that included informal education sessions and compared them to a group with no informal education sessions. The informal education sessions mirrored most ISEs in that reform-based pedagogy and inquiry instruction were explicitly used and demonstrated to the PSTs. Almost all teachers in the treatment group finished the course with more positive attitudes toward science, a willingness to plan for and include inquiry-based instruction, and included informal education in their instruction as a means to provide novel learning experiences and resources for their students.

Given that NGSS is difficult to implement for even practicing science teachers (McFadden, et al., 2021), science methods courses can similarly have difficulty supporting beginning teachers to be able to fully implement the three dimensions of NGSS, especially for elementary pre-service teachers. Many pre-service teachers have little to no science background (Clement, 1982) and the methods course they take in science will be the only exposure they have to the science education field and science pedagogy for teaching (Haefner & Zembal-Saul, 2007). As a result, elementary science methods courses have the unique challenge of teaching content and pedagogy together often with only one course with which to do so. These courses are very limited in time to cover all topics and any inclusion in the course must be demonstrated to be beneficial for the time given. ISEs have shown promise in helping pre-service teachers gain science content knowledge, confidence in teaching science (Avraamidou, 2014), and a willingness to implement the NGSS-recommended inquiry-based, student-driven instruction.

Theoretical Framework

Contextual Model of Learning

The Contextual Model of Learning (CML) was developed by Falk and Dierking (2002) as a framework for thinking about the complex and diverse nature of learning in free-choice settings such as museums. This framework describes learning as being situated within a series of contexts; personal, sociocultural, and physical, where there is a constant dialogue between the individual (personal context) and their sociocultural and physical environments (Falk & Dierking, 2002). These interactions between the contexts are continuous and ever-evolving for an individual, and the CML (Figure 1.2) can be used to capture these interactions in a descriptive way with an emphasis on context for experiential museum learning.

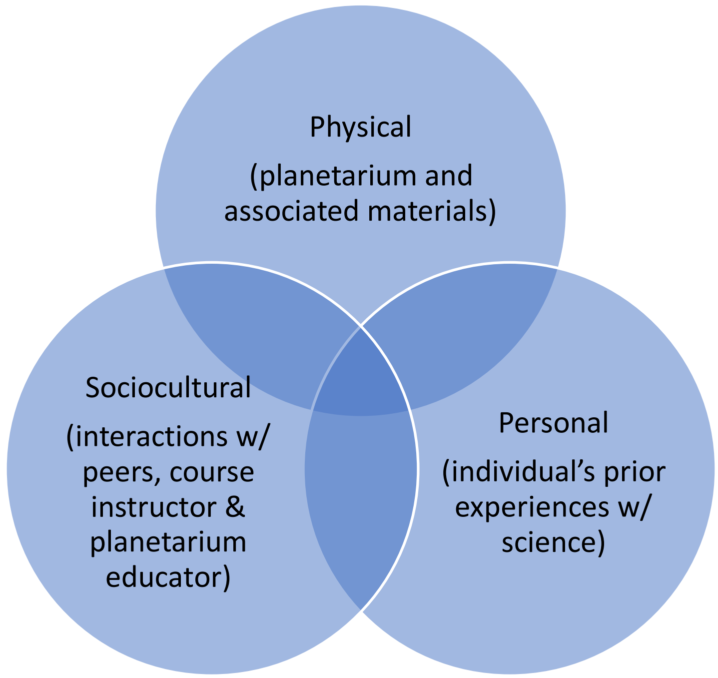

Figure 1.2. Adaptation of Falk and Dierking's Contextual Model of Learning (2002).

Personal Context

The personal context represents the background and history that a person brings with them to a learning situation (Falk & Storsdieck, 2005). The influences of prior knowledge, interests, and motivation to learn that each person has impacts their experiences in informal learning. Even the level of choice and control an individual has over their own learning in an informal environment can affect learning (Griffin, 1998, Lebeau et al., 2001). Learning in the personal context can be described as very personal and dependent on the influences described above. All visitors to a planetarium have their own personal context for visiting a planetarium, be it choice or a field trip with a broader instructional purpose in the classroom, which should be considered when developing programming and exhibits.

Sociocultural Context

Humans are inherently social beings and much of our learning is based on social interactions (Schauble, et al., 1997). The sociocultural context represents how individuals are strongly influenced by the sociocultural nature of their learning experience. The collaboration between an individual and those within their social group and/or with a museum instructor can greatly impact their learning in an informal environment (Crowley & Callanan, 1998; Koran et al., 1988; Wolins, Jensen, & Ulzheimer, 1992). Many ISEs incorporate sociocultural learning practices, such as group activities and small group discussions, into their programs and instruction to accommodate this need for social learning. While most planetariums are not conducive to sociocultural learning due to the nature of a dark dome and people remaining seated in fixed seats, some planetariums, and the planetarium experience described in chapter III for this study, incorporate sociocultural features outside of the dome to enhance the learning from visualizations inside the dome. There exists an extensive body of research for sociocultural learning theories that contain many mechanisms for sociocultural learning, but for this study, the sociocultural context of learning is operationalized to only include the interactions between the PSTs and between the PSTs with the planetarium instructor.

Physical Context

Finally, the physical context refers to the physical environment in which learning is taking place. When visitors to ISEs are asked to recall a prior visit they most frequently describe the physical context, e.g., the planetarium show they watch, the exhibits they interacted with, and the things they did while there were there (Falk & Dierking, 2000). Many things can impact learning in a physical space such as architectural design, lighting, and crowd size. A planetarium is a very unique physical context due to the large domed ceiling, dim lighting, and enhanced visualizations. Although it is important for subsequent reinforcement of things learned within a physical space outside of that space, the planetarium experience can be used as another reinforcement tool for what is learned within a PST science methods course.

Revisiting the Research Questions

Given the challenges of high-quality teaching required by NGSS, especially of multidimensional teaching, pre-service elementary teachers have a steep learning curve during their teacher training to become ready to teach science aligned with NGSS principles. In order to explore the promise of a focused, short-term, planetarium experience that fits within a standard PST science methods course, it is of interest to the field to understand how such an experience can help PSTs begin to incorporate aspects of NGSS in their lesson planning and intended implementation. Therefore, the guiding research questions for this study are:

1. In what ways can a short planetarium-enriched learning experience within a science methods course shape the perceptions of pre-service teachers (PSTs) as science learners and as future teachers of science?
2. How can a short planetarium-enriched learning experience within a science methods course inform PST perspectives of science instruction aligned with the Next Generation Science Standards?

CHAPTER 3: METHODOLOGY

Research Design

An intrinsic qualitative multi-case study was employed to study the effectiveness of a focused planetarium-enriched field experience on preservice elementary teachers' (PSTs) perceptions of the planetarium experience and how it might have helped them as learners of science and future teachers of science. As defined by Creswell, "case study research is a qualitative approach in which the investigator explores the bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving *multiple sources of information* (e.g., observations, interviews, and audiovisual material, and documents and reports), and reports a *case description* and *case themes*" (2013, p.132). Intrinsic case studies are used to illustrate a unique case that needs to be described and detailed (Creswell, 2013; Stake, 1995). The intrinsic interest of this study is that the planetarium experience is a unique feature of the elementary science methods course, due to an entire week of instruction happening in an informal environment with an expert in the field of astronomy education, who also participated in the science methods course for the entire semester. As discussed in Chapter 2, pre-service teachers are often learning the science for themselves within a science methods course alongside learning to teach the science they are learning to future elementary students. As such this represents a unique perspective to be explored in this study on science methods courses including an informal science experience with an instructor of the informal experience who has expertise in the specific science field and in the education of that field to include as part of the science methods course. Each case is one of the five pre-service teachers who volunteered for a post-experience interview in an elementary science methods course (of 13 PSTs who consented to the study) that attended a planetarium-based field experience where a deep dive into select portions of the Earth and Space Science standards took place with explicit detail of the Science and Engineering Practice (SEP) of modeling and the Crosscutting Concept (CCC) of patterns. For this study, each PST who volunteered to be interviewed is considered a case. The unique perspectives of each teacher and the amount of data collected on these PSTs allow for each PST to be considered their own case but are categorically bound within their shared methods course, and participation in the planetarium experience.

Participants

Pre-Service Teachers in an Elementary Science Methods Course

This study focused on five PSTs enrolled in an elementary science methods course for undergraduate students at an urban, southeastern, public university in their fourth year immediately before their last semester of student teaching. The study also included additional data beyond the five cases from the remaining eight PSTs in the same science methods course who were not individually interviewed. In the semesters before this methods course, the PSTs were to observe in placement elementary classrooms in public schools in the area and to teach one lesson in their placement classroom per university education class; typically having taught or co-taught three to four lessons by this point in their education program.

This cohort of PSTs began their program during the fall of 2020 when COVID-19 was most disruptive to educational institutions. As such, many of these PSTs did not have physical placement classrooms as part of their teacher preparation program and only experienced online instructional observations. They did teach a few (three to four) lessons virtually in their placement classrooms prior to the science methods course. This elementary science methods course was the first semester these PSTs experienced in-person instruction in their education program. The methods course physically met in a local public elementary school where there was a classroom for the science methods course. Some of the elementary teachers would block out time in their classrooms during the methods course for the PSTs to teach a short science lesson to their elementary students. These teachers' classrooms will be referred to as the clinical classroom. Groups of seven to eight PSTs would plan lessons and then together teach that lesson in a clinical classroom, before returning to the methods class to reflect.

The science methods course focus was to introduce the preservice teachers to NGSS and the three dimensions through learning as a student the science material and best practices for teaching the science material to elementary students. The pre-service teachers were reflective of the national demographics for elementary teachers with a majority being white women (NCES, 2023). The racial and gender demographics of the five target cases were three White women, one Black woman, and one Black man. The remaining eight PSTs in the course were all white women.

Planetarium Educator Reflexivity and Positionality

I am the planetarium educator who led the instruction during the planetarium-enriched experience due to my expertise in the field of astronomy and my experience in teaching astronomy to elementary students and preservice teachers. My expertise made me a good candidate to not only lead this experience but also to study this experience.

Due to the qualitative nature of this study, many of the interpretations made during the analysis of results are informed by my expertise described here. I have a Bachelor of Science in Physics with an emphasis in astrophysics. I also have research experience in the field of astrophysics. I have 15 years of planetarium experience and seven years of formal planetarium education experience educating approximately 2500 elementary students per year. I received a Master of Arts in Middle School Science and High School Physics with accompanying teacher certification in those fields. I also taught the planetarium-enriched experience to pre-service elementary teachers in their science methods courses for three years prior to the implementation of this study.

I have developed and implemented several curricula for the planetarium for both in-dome and out-of-dome experiences with a heavy focus on NGSS-aligned instruction. The programs I was a part of were grounded in the goals of NGSS such as phenomenon-based instruction and sense-making, by providing visualizations for students to experience natural phenomena, then engage students through discussions and physical modeling as a sense-making tool. I also believe that science instruction should utilize SEPs while also highlighting the CCCs for clarity and unity between science topics.

These attributes make me uniquely positioned to teach this planetarium-enriched experience in a way that is not typical in most planetariums. Planetarium programs like this are often taught by astronomy professors or undergrads who have no formal training in K-12 teaching (Schultz & Slater, 2020). These planetarium operators also typically lack experience working interactively with elementary students or elementary teachers due to the typical formal nature of planetariums where students are sitting in rows, facing forward, and the presenter leads through direct instruction only or a pre-programmed show is played (Thornburgh, 2017). I have the training, knowledge, and experience in astronomy, working interactively and informally with thousands of elementary students and many pre-service elementary teachers, that provides me a unique perspective on some best practices for teaching astronomy to elementary students in an NGSS-aligned way, inside and outside of the planetarium dome.

Study Context: Planetarium-Enriched Experience

The planetarium-enriched experience was hosted at the university's planetarium, which features a state-of-the-art fulldome environment that uses a 360-degree projection system for an immersive visualization experience of astronomical phenomena. The experience was a two-and-a-half-hour lesson that constituted a week's worth of instruction and was taught by an experienced planetarium educator.

Overview of Planetarium-Enriched Experience

The entirety of the planetarium-enriched experience existed within the physical context of learning as it relates to the theoretical framework, the Contextual Model of Learning (Falk & Dierking, 2002) because this experience existed within a planetarium, using materials provided by the planetarium instructor. PSTs had choice in how they engaged within the physical context of the planetarium by choosing how they participated in each phase of instruction. These choices throughout the experience are based on their personal context of learning, which can be influenced by their prior knowledge or interest in the subject or activities. In addition, the Contextual Model of Learning detailed that people within an informal learning environment are strongly influenced by interactions within their own social group and outside their social group like with a museum instructor. During these two phases of the planetarium experience, there were purposefully designed, planned interactions between the PSTs, and between the PSTs with the planetarium instructor to be socioculturally situated. Thus, the planetarium-enriched experience was purposefully designed with all three contexts of learning in mind.

During the first phase of planetarium instruction, the PSTs learned about the CCC of patterns and the SEP of modeling along with the progression charts (Appendix A and B) for age-appropriate benchmarks for understanding (*NGSS Appendices*, 2013). The PSTs had been familiarized with the NGSS standards and how to break apart the three dimensions within a standard as part of their methods course instruction. I introduced them to the four standards we focused on for the day: two for the K-2 grade band (1-ESS1-1 and 1-ESS1-2) and two for the 3-5 grade band (5-ESS1-1 and 5-ESS1-2).

In phases 2 and 3, the PSTs experienced the planetarium educator's implementation of two modeling approaches, an immersive visual model in the planetarium dome and a hands-on physical model in the classroom outside of the planetarium dome. These instructional phases included multiple instances of explicit pedagogically-focused commentary and extraction of the modeling practice and the crosscutting concept of patterns. Thus, the PSTs vicariously experienced part of the cognitive task of pedagogical planning and implementation done by the planetarium educator so that they might become attuned to what they might do as future teachers.

In Phase 4, the PSTs explicitly unpacked the instructor work that preceded their planetarium experience and planned a lesson for teaching the same content to their future students. The sequence of instructional phases was intended to provide a direct and well-structured experience that modeled and actively explored with them some of the tasks they would engage in as teachers. Participant experiences guided by each of these four phases of the planetarium-enriched experience are further detailed below.

Phase 1-Exploration of Practices and Crosscutting Concepts

Instruction began with a short review of the SEPs and CCCs within NGSS with an explicit focus on their importance in science (approximately 20 minutes). Their science methods course previously discussed the SEPs and CCCs, so the intention was to review these and identify the target of each for the upcoming planetarium instruction. I identified modeling as the target practice and patterns as the target crosscutting concept for the day. We reviewed what modeling is and how it is used within NGSS, by me describing what modeling is, and the different types of models that are beyond physical models. Then I showed and described the modeling progression (Appendix A), which describes what students should know about modeling and what they should be able to do with modeling in grades K-2 and grades 3-5 grade. I also provided specific examples that I had seen in my prior experiences working with students in these grade bands. Then PSTs reviewed what patterns are crosscutting throughout NGSS. Again I showed and described the progression of patterns (Appendix B) from grades K-2 and grades 3-5 with more of my specific examples.

Phase 2- Planetarium Formal In-Dome Segment

First, the PSTs engaged with a 10-minute segment of a fulldome-produced planetarium show, Perfect Little Planet (Clark Planetarium Productions, 2012), targeted at elementary students as a demonstration of the capabilities of a planetarium and later related to their teaching standards. The show contained a complete tour of the solar system and the segment shown focused on the outer planets and a few moons. Instruction shifted from the produced show to fulldome live interactive instruction with three-dimensional visual modeling of the Sun, Earth, and Moon and a focus on the patterns of these three celestial objects (approximately 45 minutes). Instruction was taught at a middle school level so teachers could engage as students in what will be referred to as "student-mode." I focused on patterns both from an Earth-based perspective and then switched to a space-based perspective, which is outside the bounds of the elementary standards but would provide the teachers with more knowledge about the Sun-Earth-Moon system. The virtual simulation showed Sun motion throughout the day, star motion at night, and Moon motion and shape over the course of the month. The Earth-based perspective showed a visual model of what is seen on Earth if the PSTs took their own data from outside, while the space-based perspective allowed for a visualization that cannot be achieved without a model. The planetarium is uniquely situated to accommodate both perspectives in an immersive environment which is beneficial in creating spatial awareness.

The teachers were introduced to the dome as a type of model that has strengths and limitations but is useful in depicting phenomena that cannot be seen outside in real-time. I explicitly established components of the model by articulating that each preservice teacher is their own Earth and the screen is the sky overhead that depicts the sunrise and sunset over several days. I explicitly drew attention to the pattern of the Sun's daily motion, and then ideas were elicited to describe why this pattern happens. The same was shown with the Moon on the screen over the course of the month with explicit detail on the shape of the Moon's phases and further discussion on recognizing the pattern. Finally, I showed the height of the Sun throughout a day for each of the four seasons to highlight the differences in the seasonal length of day and height of the Sun for different seasons.

After the observations of each pattern concluded, the PSTs were encouraged to generate causal explanations for these patterns. I drew on their ideas and responses to the ideas with purposeful questioning of their mental model of the Sun-Earth-Moon system. Both the terms and concepts of modeling and patterns were used frequently throughout this phase through discussions about how students need to establish pattern recognition of phenomena on their own. I repeatedly described how elementary students need to experience the phenomena first-hand several times through real-world observations or modeling if necessary before sensemaking can begin to explain the phenomena. The process of observing repeatedly is necessary for students to see the pattern and students will need to see the pattern more times than the PSTs would as adults (de los Santos, 2017). I also described the importance of developing the model with students so they can see the mechanism behind what parts of the model are accurate and what parts are inaccurate to reality.

Phase 3- Planetarium Formal Out-of-dome segment

This student-mode continued from a formal in-dome experience to a formal out-of-dome experience (approximately 45 minutes). This phase focused on physical modeling of the same concepts that were explored visually in the dome.

Stage 1 Pedagogical Framing of Earth-Sun Model

The out-of-dome experience began with a pedagogical discussion about when working with elementary students engaging in modeling it is important to be explicit in detailing the components of modeling while guiding students through either teacher-developed models or student-developed models, which both have value. The modeling process is iterative and the components consist of developing, evaluating, and deploying a model (Hestenes, 1987). We discussed how students might develop a model and allow students some free reign to try different (appropriate) components when building their model, which may be different what the PST had in mind or had planned. For example, I described the many times I have developed the Earth-Sun model with elementary students and how students may choose different objects (e.g. a yellow paper Sun, or a picture of Earth) than I have prepared or that I know will not be as efficient as my spherical globe (for Earth) and lamp (for Sun) model. I detailed how I allowed students to try with their materials anyway, but eventually, students saw the benefit of using the lamp as the Sun as opposed to say a piece of yellow circular paper, which students often try first. Then as a whole group, we focused on hands-on physical 3D modeling of the Sun-Earth system and how they interact. We discussed components of their model, the potential representations of the Sun and Earth, and the benefits and limitations of the representations they chose.

Stage 2 Interactions of Earth and Sun

The PSTs then engaged with the model and the components consisted of lamps (Sun), globes (Earth), and markers of the months laid on the floor in a circular arrangement around the base of the lamp (Sun). Many teachers tried to use other objects available to them to represent the Sun/Earth/Moon but all had switched to using the same model, using the lamp and globes due to that model being more intuitive. Instruction focused on the patterns in our sky and the teachers built their own physical models in small groups to explain a given phenomenon. The activity used hands-on learning for teachers to create a physical model of the Sun-Earth system from a space-based perspective to describe different phenomena such as day/night and sunrise/sunset. The activity demonstrated guided inquiry instruction by the instructor guiding the PSTs through purposeful questioning as they developed and deployed their model in new situations such as adding the Moon (Styrofoam sphere) into their model for them to incorporate. During this phase, I formatively checked their understanding by asking for each group to model a sunrise, full Moon, and motion of the Earth over a year.

Stage 3 Pedagogical Discussion of Modeling Sun-Earth-Moon

After the group physical models of the Sun-Earth-Moon system were established, we stepped out of student-mode and into teacher-mode to have an on-the-spot pedagogical conversation where I highlighted the ways I was questioning, formatively assessing, and adapting instruction based on their needs. This was also a lesson that can be taught at different elementary grade levels because the core of the lesson is a "Disciplinary Core Idea" with a storyline throughout the NGSS standards (NRC, 2011) and thus the target SEP and CCC used in the lesson must be age-appropriately incorporated. This discussion focused on pedagogical techniques used during their lesson and how the lesson was more complex than they will use in their classrooms and the age differences between their students will lead to different ways to adapt the lesson to be age-appropriate. We also discussed ways to formatively assess student-identified models and patterns like when I had the PSTs develop their own model and then asked them to demonstrate what a full Moon would look like with their model. Teachers could arrange the model however they felt appropriate and I came by to assess for myself if everyone was in agreement. On occasion, one or two of the groups were not modeling correctly so

I would ask them all to demonstrate a task at the same time, and then they could look at the differences in groups and argue for why they were positioned the way they were. We could reason out which models made sense and which ones were modeling something different/inaccurately. We also discussed allowing students to develop their own models/patterns using many materials instead of creating a cookbook lab for students to do.

Phase 4-Transfer Experience to Their Future Students

Stage 1 Whiteboarding Plans for Future Students

The final activities had the PSTs move into "teacher-mode" (approximately 30 minutes). The PSTs were divided into groups of future K-2 and 3-5 grade band teachers, based on their preferred grade band. After each group was given the specific grade band standard or the foundational concepts that precede the middle-level version they just experienced (ESS1.A), in small groups of three and four they whiteboarded ways to teach the space science content and pedagogical techniques to their grade level. The groups were asked to whiteboard an outline of how they would teach the standard and how they would incorporate the practice of modeling and the crosscutting concept of patterns in their lessons. The firm boundaries of explicitly requiring the PSTs to include an SEP and CCC were included to show that these must be considered in every unit of science they will teach. Then the groups shared out ideas and techniques for integrating modeling and patterns into their lesson/unit with guidance from me on potential pitfalls or issues that can arise in their instructional plans.

Stage 2 Post-Experience Survey

Finally, the PSTs took The Post Experience Survey included in Appendix C which is discussed below in the data analysis plan (approximately 10 minutes, after class had ended). The survey asked the PSTs to reflect on the planetarium experience and how it impacted them as a learner of science, a future teacher of science, and how the planetarium could impact their future students.

Data Collection

Post-Experience Interviews

From one-three weeks after the planetarium-enriched experience, five PSTs opted in for a stimulated interview (Appendix D) to reflect on their answers to the Post-Experience Survey (Appendix C), reflect on past experiences, and foresee their future teaching science and how, if at all, the planetarium experience impacted their views. These stimulated interviews were semi-structured and lasted around 10-15 minutes. I provided the PSTs with their written responses on the Post-Experience Survey to refresh their memory and so they could clarify/expand on their answers, or change their answers due to more time and reflection happening since the experience took place. The additional interview questions were developed in order to provide insight into the research questions of this study, with another expert qualitative educational researcher. These additional questions were developed to triangulate with the other sources of data collection to target how the planetarium experience might have served as a direct model of NGSS-aligned instruction to positively influence their future visions of science teaching.

Audio/Video of Planetarium-Enriched Experience Phases 3 and 4

During Phase 3 and 4 of the planetarium-enriched experience, video was taken of the experience using a camera within the dome and four cameras on opposite sides of the classroom, during the out-of-dome phases to help capture small group discussions. Phase 3, the video captured PST conversations as they engaged as students using physical modeling to describe patterns in the sky including questions asked, responses to my guiding questions, and as they worked through developing their model. In Phase 4, PSTs worked in small groups to plan appropriate instruction for their future grade band of students using the same DCI as they experienced in Phases 1-3. Phase 4 videos captured PST conversations as they planned for their future students to meet their NGSS performance expectations, and input from other groups and me on those plans. Audio and video were captured and then transcribed to help inform the 5 cases of interviewed PSTs to characterize their behaviors during the planetarium experience through memo-writing of the transcripts.

Post-Experience Survey

At the conclusion of Phase 4, PSTs took the Post-Experience Survey (C). The survey asked the PSTs to reflect on specific parts of the planetarium experience and describe how, if at all, it helped them as a science learner and as a future teacher of science. The Post-Experience Survey starts with a list of each aspect of the planetarium-enriched experience to remind them of what transpired and to focus their answers for each question on a specific aspect of the experience for different types of learning. These questions were pilot-tested on science methods students who were not participants in the study and refined based on feedback from four other expert qualitative educational researchers. This survey (see Appendix C) of experiences in the planetarium was administered proximally immediately when the PSTs finished the planetarium experience with the purpose of capturing how the specific parts of the planetarium-enriched experience shaped what they learned and influenced how they would plan for, and ultimately do, in the classroom. The purpose of the survey was to determine which aspects of the planetarium were most impactful for their own science learning, for their future science teaching, and for their future science classroom.

Pre-Video

A week before the PSTs came to the planetarium, a pre-video was administered. The pre-survey consisted of a Flipgrid video question to which each student responded by recording a video of up to three minutes where they answered the question, "As you think about your future as a teacher of science, describe your vision of what your students should learn about science in your classroom." The purpose of this question was to elicit their initial thoughts about what quality science instruction meant to them and how they specifically planned to implement this in their future classrooms.

Methods Class Observations

The science methods class was held one day each week for 2.5 hours for the 15-week semester, and the planetarium experience was held during one of these class sessions. The chronological sequencing of data collection is shown below in Table 3.1. The goal of instruction during this course ranged from learning science content to learning science using experiments that can, and often are used at the elementary level. Throughout the duration of the course, I was present in the classroom to document and characterize the experiences of the participants during their science methods course through observations and scripting. Rather than using an a priori observation protocol, in order to capture the lived experiences of PSTs, I scripted the topic, or topics, of each class, who and how the PSTs were engaging in the topic, and the duration of time spent on each topic. The field notes taken during observations provided opportunities to capture what was happening in the classroom, such as specific lessons, student discussions, student participation, etc. The purpose of the observations was to capture the five cases of this study and highlight their behaviors within the methods course to help compare to their behaviors during the planetarium experience. Characterizing the cases' behavior is also why observations continued in the methods course after the planetarium experience had concluded.

Data Collection Timeline

Table 3.1
Timeline of data collection

Week				
1-3	**4**	**5**	**6-8**	**9-15**
Methods class observations				
	Pre-Survey	A/V of Planetarium experience (proximal)	PST Interviews	
		Post-Experience Survey (proximal)		

Data Analysis Plan

A multi-case study was employed for this study to examine the data collected among cases to inform how the planetarium-enriched experience affected PSTs collectively and distinctly. The multi-case study is not about teacher learning of science material or the planetarium experience alone. It is a study of the cross-section of PST perceptions of learning within a planetarium-enriched experience as part of their science methods course. This multi-case study consists of the analysis of the five cases (the five PSTs who agreed to an interview) in two steps. First I did a within-case analysis described below, which was then followed by a cross-case analysis to highlight distinctions and commonalities between the cases. After thorough analyses of the five cases, the more limited data (absence of follow-up interviews) of the remaining eight PSTs in the course who had the same planetarium-enriched experience was summarized to explore any possible patterns of similarities or differences to specific results from the five cases. The analysis below is listed in order of significance to the study.

Step 1: Within Case Analysis

PST Interviews

Five PSTs out of 13 in the methods course opted to be interviewed about their planetarium experience with additional questions about their past and future science instruction (Appendix D). These interview transcripts were transcribed through line-by-line open coding where I began with the first interview and went through the interview transcripts line by line and highlighted important thoughts into different colors to represent potential themes or topics. An example of this process is shown below in Figure 3.1, where I went through the transcripts of the first student-created video for the pre-survey, highlighted codes when they arose, labeled the code at the top of the page of all transcripts, then changed colors to highlight new codes when they arose.

Hands-On
Guiding Questions
Group Work
Student-led
Addressing All Student Questions/Ideas
Interactive Lessons
Connect to real world
Science is everywhere

Potential emergent topics from (partial) transcript below

So, in my future classroom, I want to include a variety of hands-on activities, and I think this is so crucial because students are way more engaged with the lesson when they are able to experiment with the content themselves. And I've noticed a lot in my placement this semester that my first-grade students enjoy their science lessons a lot and like their levels of curiosity are so high. They always get like really into the lesson and ask so many questions. My mentor teacher does a great job answering them and asking them like: "What do you think?", "What do you think the answer is in your own opinion?" And they also work in groups a lot when they're introduced a new topic and my mentor teacher has them collaborate with each other to determine what they think the answer is. And I love this, and the students seem to love it too, so I definitely plan on incorporating this in my science classroom as well. Like pairing the students up and having them like discuss the content first and what they think about it instead of me just like teaching it to them. And in my future classroom, I also want to ensure all my students questions are addressed. Like I want to write them all down. If we didn't get to them during the lesson so I am able to go back over them with my students at a different time. And I really want my students to feel as if their questions are of high value and I want them to realize how much their voice matters in my class.

Figure 3.1- Example of open coding of first pre-survey

Then I moved to the next interview and used the same color highlighter when the same corresponding topic came up or introduced a new color if a new code arose to establish codes of common PST perceptions. Then once I had coded all five cases I further collapsed these codes into themes based on the responses to their past experience in science instruction, their learning during the planetarium-enriched experience, and how the experience might have shaped their future teaching of science. Finally, I aligned the themes to the conceptual framework that underpins this study. An example of this process is in Figure 3.2 below. Here I included the codes and a representative quote and I aligned that to a broader theme and how that theme fit within the theoretical framework of the Contextual Model of Learning.

Pre-Survey: "As you think about your future as a teacher of science, describe your vision of what your students should learn about science in your classroom." Responses in Flipgrid.

Themes	Codes	Quotes
Student-Centric (Intersection between Personal and Sociocultural Context)	Addressing all student questions/ideas	"I really want all my students to feel as if their questions are of high value and how much their voice matters in my classroom." -1
	Guiding questions	"Using those engaging questions… just to get their minds rolling and to just question and guide them in the same way instead of depending on lecture and notes" -4
	Student-led	"Normally a lot of the lessons are teacher-led and students just kinda sit there and absorb the knowledge and it's not always beneficial…I want my lessons to be student-led if at all possible." -15
Phenomenon-Based (Physical Context)	Hands-on	"I want my students to have a variety of hands-on activities they can use to learn and explore…. I don't want to ever be standing up in front of the room and having to tell my students things" -11
	Interactive Lessons	"I hope to make science as interactive as possible. One memory I have as a young science learner is once it was time for science we would get our science textbooks, find definitions of terms in the glossary, and copy it down in our notebooks. This was easy but it didn't cause anything to stick with me. I hope to make my future lessons interactive so they can engage in the topic we are learning. -5

Figure 3.2- Grouping and aligning codes to a theme within the theoretical framework

Audio/Video Analysis in Phases 3 and 4

I analyzed Phases 3 and 4 of the planetarium-enriched experience through memo-writing while watching the video and pulling quotes from the transcripts, to help characterize the individual cases where possible to see how they engaged in their various small group activities. I documented comments, actions, and reactions based on a review of the video and transcripts with an explicit focus on the five primary participants. This helped to characterize each case further for their behaviors, questions, and responses during the planetarium experience and how that compared to their behavior in the traditional science methods course. Analyzing these similarities and differences helped to identify how the planetarium experience might have altered their perceptions as a science learner or future teacher of science.

Analysis of Post-Experience Survey

The Post Experience Survey (Appendix C) was analyzed to identify helpful aspects of the planetarium for both of the types of learning they experienced; as a science learner, and as a future teacher of science. Then I identified codes within the responses for which parts of the planetarium experience were helpful for which type of learning (as a science learner or future teacher). I identified the codes by line-by-line coding of the first survey, similar to the process shown in Figure 4.1, for which part of the planetarium experience was effective for both types of learning. Then continued open-coding through the other surveys. During this process, I also allowed for new codes to be developed if a different part of the planetarium experience was effective for the respective type of learning. Then I collapsed these codes into themes aligned with the specific contexts (physical, social, and personal) of the conceptual framework, the Conceptual Model of Learning (CML) (see Figure 1.2).

Pre-Videos

The pre-surveys (videos created by students) were analyzed first by line-by-line coding where I went through the first transcript of a pre-survey and highlighted each new response as a code, then coded the other PST responses. I also utilized open coding so if new codes arose, I would highlight them in a different color and then continue coding until I was through all pre-surveys. I determined saturation was reached when I saw most PSTs answered the question in similar ways and no new information was being provided. These codes were then aligned to specific contexts of the conceptual framework, CML

Methods Class Observations

Observations were analyzed by memo-writing about the 5 cases of the study, documenting physical behaviors and auditory responses during the methods course. The observations served multiple roles: becoming more familiar with the students that I taught so they would feel more comfortable engaging in the upcoming planetarium field experience and interviews, and to inform some of the context of what students discussed in their surveys and lessons. I also used the observations to detail more about the 5 cases to highlight the similarities and differences in their behavior in the methods course and at the planetarium experience. These observations were used to establish the case context of the methods course to acquire a deep perspective into the overall context of the science methods class experiences of the PSTs in order to contextualize the learning and perceptions of the PSTs to the planetarium-enriched instruction.

Profile of Each Case

Once all analyses were completed I created a profile of each case defining a narrative timeline of their past experiences with science instruction as a student or during their teacher preparation program, their journey through the planetarium experience, their reflections on their learning from the planetarium experience and their perceptions on how the planetarium might have shaped their future ideas and goals around teaching science.

Step 2: Cross-Case Analysis

Once the profile of each case was established I compared the interviewed cases for similarities and differences in responses to learning, goals, and ideas for future science instruction. I narratively compared and contrasted the five interviewed cases based on responses to the pre-survey, behaviors during the planetarium experience, responses on the post-survey, and responses in the stimulated interview. This analysis helped to characterize the common behaviors of a typical PST, and how they can differ based on comfortability in science or comfortability in teaching. Then I analyzed the other post-survey responses (eight non-interviewed PSTs) through open coding and compared their coded responses to one or more in-depth interviewed cases.

CHAPTER 4: RESULTS

This chapter first presents results from the five cases by narratively describing each case using illustrative quotes and learning samples. Explicit attention in the presentation of each case is incorporated to emphasize how their planetarium-based experience aligns to learning framed by components of the theoretical framework (see Figure 1.1). The results from the remainder of the PST participants for whom there is less extensive data are then presented as a group and briefly compared to those from the five more in-depth cases.

Amber

Prior Personal Context

Amber (all names are pseudonyms) is a pre-service teacher who was active in class and seemed to take teaching and developing lessons seriously because she often redirected her off-task peers during lesson planning with her group in her science methods course. She described her science background as extremely limited but seemed intent on developing her ability to teach science in the future since her behaviors during science methods tended to be focused and on task. “I think science isn't my strong suit. As a kid, I didn't have a lot of experience and I haven't had a lot of education in that [science] or like the things that we're covering now [force and motion].” She described much of her previous K-12 experience in science as bookwork that did not include much inquiry-based instruction. “Hands-on activities is something that I lacked in my school experience, and I think it really would have helped me to better understand what we're learning and how things [in science] work together."

One experience with limited instruction in science happened during her Kindergarten field placement classroom during her science methods course.

> So in my like field placement, I haven't really seen a lot of science, just math and English…They just started weather like last week, and they read a book at the end of the day, like one of those really giant ones about clouds. But that's the only science I've seen in my program. (Amber, interview)

Amber's experiences of science instruction were apparently both rare and superficial, both in her own elementary school learning as well as in elementary field placement experiences as part of her science education program. When science instruction did happen during her field experiences as an education student, it typically was reading a book at the end of the day and was several weeks behind the district-provided curriculum schedule.

With limited science experience as a science student and limited exposure to quality science instruction implemented in elementary classrooms as a PST, Amber's perceptions of future science classrooms may have been likewise limited. When asked about her vision for her future science classroom before coming to the planetarium, she said that she wanted only hands-on activities with no teacher-led lessons.

> I want my students to have a variety of hands-on activities [in science] they can use to learn and explore … I don't want to ever be standing up in front of the room and having to tell my students things or have my students in lines and rows. (Amber, pre-video)

Although hands-on activities and other techniques for supporting active student engagement are needed for science students to meet NGSS performance expectations (NRC, 2011), Amber's responses in her pre-survey did not include specific examples of how hands-on activities equated to quality science instruction. She may not necessarily know or only knows superficially that hands-on learning alongside other techniques can support active student engagement. Her response also highlighted what may be a preconceived notion that teacher-led instruction is bad and should be avoided, but there is sometimes a need for direct instruction in quality science instruction even in the younger grades (Lazonder & Wiskerke-Drost, 2015).

Physical Context of Learning in Planetarium Experiences

In contrast with her active involvement during the science methods activities in general, Amber remained reserved during each phase of the planetarium experience. She stood at the back of the class during whole group discussions, did not answer whole group questions, and rarely manipulated the physical modeling of the Sun, Earth, and Moon. Instead, she let her group members try to figure out the Sun-Earth-Moon system. Her stated lack of experience in science and with the space science material might have prevented her from speaking up as she normally did during the regular science methods class and could have caused her to hesitate from directly participating with the physical model.

The planetarium experience differed from the science methods class because the focus included learning the science content at a middle school level instead of mainly focusing on how to teach the science content at the elementary level. For example, during Phase 4 of the planetarium experience, the PSTs worked in small groups to plan a lesson for their preferred elementary grade band that would target the content that was the focus of the planetarium experience. The planetarium experience was targeted at a middle school grade level, and the group planning activity was designed to get PSTs to think about teaching similar content to younger children. Amber's group chose the K-2 performance expectation of 1-ESS1-1—"use observations of the Sun, Moon and stars to describe patterns that can be predicted." As seen in Figure 4.1, we can see that Amber's group lesson had students involved in a whole-class activity where the teacher wrote student ideas on the board and only the teacher demonstrated day and night to students instead of students working in groups to figure out day and night on their own. Although Amer's whiteboarded lesson was part of a group effort, she took the lead in planning the lesson based on video analysis and she took charge of writing the lesson on their group whiteboard.

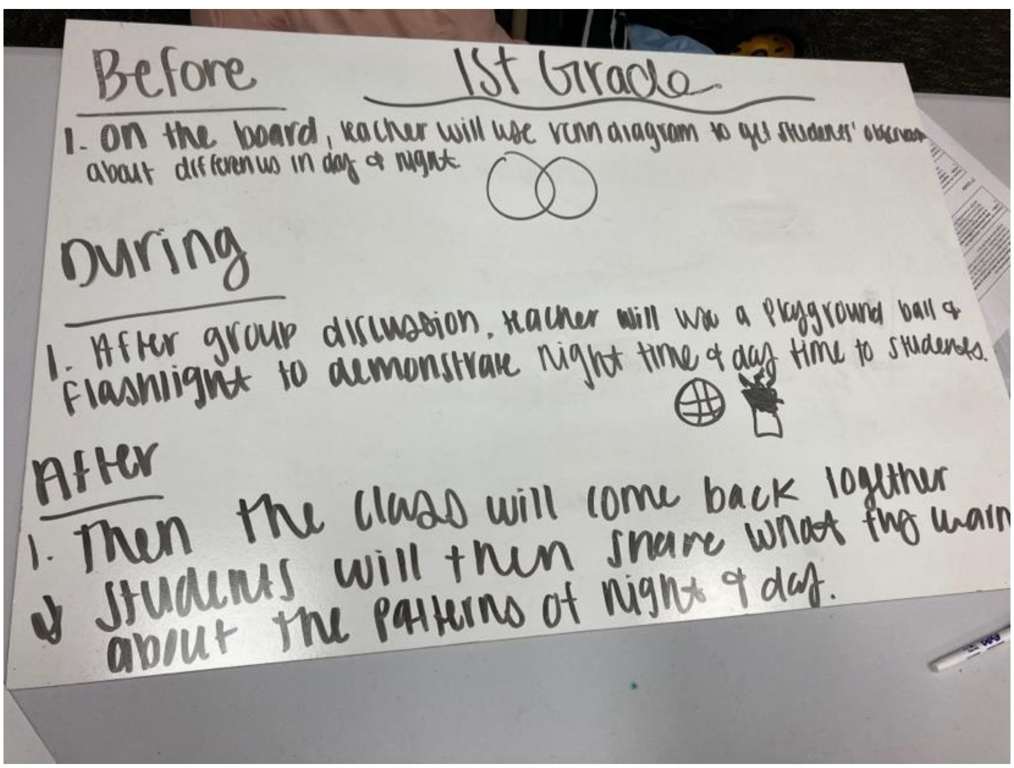

Figure 4.1. Amber's group planned lesson to teach night and day to first-grade students.

Amber's group description of the lesson contrasts with her vision for her elementary science lessons as including a "variety of hands-on activities they [students] can use to learn and explore" without her ever "standing up in front of the room and having to tell my students things." Amber knew superficially what good science pedagogy could include when she discussed her vision for her future science classroom but seemed to be reluctant to implement that pedagogy when it came time to plan her own lesson, possibly due to her self-described limited science knowledge and limited experience with science instructional practices in the classroom. Amber's experience with planning the lesson is similar to what can be found in the literature where inexperienced elementary teachers revert to teaching the way they were taught, which is almost exclusively through traditional teacher-centric methods instead of the student-centric inquiry-based instruction that they know to be more effective (Nowicki, 2012).

Characterize Planetarium Compared to Prior Personal Context

After the planetarium experience, Amber expressed a change in her vision of her science classroom from vague generalities to more explicit ideas to incorporate.

> I think it's [her vision of her future science classroom] changed in terms of like I know now, like what good examples of learning for them are, like what resources there are to provide them with. And just because I'm not comfortable with [the science content] doesn't mean I should take away from them the opportunity to learn it. (Amber, interview)

One of the key takeaways she had from this experience was how to use hands-on activities in specific ways to advance particular learning goals for her students.

> Even just using physical modeling [using lamps and globes during planetarium experience], there's things I now know how to do. I can do that with them to help stick it in their brain. I want my students to have hands-on experiences and this showed me as a student and as a teacher how modeling can impact others. (Amber, interview)

Future implementation of her stated goals of having a student-centric classroom now can draw from a tangible example of how to do modeling [in space science, in this case] in an elementary classroom, and why it can impact her students. She stated that she now knows how to design some hands-on experiences for her students and also knows that such experiences can be impactful on learning from her personal experience at the planetarium.

Amber also realized the importance of using multiple representations when modeling to give students a clearer picture of the phenomena under investigation.

> I think this [planetarium experience] showed me the importance of [using] modeling [in] my teaching in different ways [in addition to the physical model described above]. Going forward, as a teacher, I would want to use that visual representation [on the planetarium dome] because I think it would help them understand to watch it goes like this … [motioning sunrise/set]. It was the most helpful for me based on how I learn and in turn how my kids learn because they get to [visually] see it happen. (Amber, interview)

She found the importance of using the visual representation of the Sun/Moon motions helped her to refine her own understanding, and by extension would likely help her future students. She also recognized that just one model was not as effective for learning as using both a visual model and having students engage with a physical model.

> [The visual model] helped me like I could see it and then we planned our own model with the light bulb. We got to move and do all of that, and I think that reinforced what I've already learned. Like, I want to do that with my students to help reinforce like what I'm saying and then them doing it. (Amber, interview)

Finally, Amber found the resources the planetarium provided, which she was not familiar with, to be beneficial for her future science instruction.

> I didn't know that they have field trips at places like this. And so like anywhere I teach I want to be doing research on where those places are, how can we get there? How can they come to us because I'm not comfortable with [the material]? (Amber, interview).

She identified one benefit of using informal learning venues to be that the instructors in those spaces are more knowledgeable than she is on subjects, such as science, that she said she struggles with. She would use informal educators as a resource in her classroom to supplement her instruction.

> I think like you did a great job at explaining it to us and making us feel like as teachers, we have these resources and … it's not easy to do right, but we can do it. And there's places like [the planetarium] that we can do or like the way you approached, asking questions or making us feel included. And I know that if the students had a question they would get an answer. (Amber, interview)

Summary of the Case

To summarize, Amber's personal context of learning in science prior to the planetarium-enriched experience she described as being superficial, with her own K-12 experience being teacher-centric with mostly bookwork and no hands-on activities. Her personal context pre-planetarium included her future vision of her science classroom being different from her lived experience where she would have only hands-on activities and no teacher-centric instruction. She seemed to equate the teacher-centric instruction she received as a K-12 student as the reason she did not receive great science instruction and therefore she thought that teacher-centric instruction should be avoided.

Her physical context of learning within the planetarium differed from how she typically engaged during her science methods course; she was more reserved at the planetarium than she usually was in the methods course. This could be because of the strong planetarium focus on first learning the relevant space science concepts which she indicated she did not feel that she knew well. This could have influenced her behavior to not put herself or her ideas out there because of her perceived discomfort with science.

After the planetarium experience, she expressed a change in her vision of her future science classroom because the planetarium experience gave her a tangible example of how to use modeling through multiple representations. She highlighted her new perception that a variety of representations are needed within her future science classroom to help students with the sense-making of phenomena. Her perceptions of the learning value of visual models led her to express a desire to use visual models to show students a natural phenomenon that they can then use other modeling (e.g. with physical materials) as a sense-making tool to explain the visual representation. Finally, she seemed to express relief in knowing there are resources and people out there that can help her with her science content, and even if she is uncomfortable with science she wanted to seek those resources out for the sake of her future students so they can receive quality science instruction which she did not have as a student.

Madison

Prior Personal Context

Madison was quieter than most other PSTs in the methods course but appeared to be more comfortable when they began to work in elementary classrooms with elementary students in the group-led lessons as part of the methods course. During whole-class discussions in the methods course she did not often share out and when they planned lessons to teach in the elementary classes, she usually did not share her own ideas for how to teach the lesson but would comment and build on the ideas of other PSTs. When the small groups of PSTs would teach their lessons to elementary students as part of the course's fieldwork, she quickly found elementary students to help individually or used guiding questions during student small groups, whereas other PSTs would mostly seem more reluctant to engage with students individually. Many of the lessons the PSTs developed for the elementary students were hands-on and required active student participation. She was possibly more comfortable with working with students in an active learning environment because she felt she had good examples of science instruction in her own K-12 experience:

> I always was so engaged in my science classroom [when I was an elementary student], like with my elementary teacher, because we would do things like egg drops and experiments and stuff. But then when we went to our science special

area [in elementary school], we got to do even more experiments. So just like the hands-on activities of creating circuits and doing stuff like that, that was the most effective [science instruction for me]. (Madison, interview)

She perceived the multitude of hands-on activities and active learning experiences in her K-12 classroom as beneficial for her learning because she described herself as being more of a hands-on learner.

Prior to coming to the planetarium experience, Madison had jotted down ideas for how the Moon phases occur (Figure 4.2)[one of the topics to be explored in the planetarium experience], which was a PST-developed activity during a class-assigned PST presentation in the science methods course. As seen in Figure 4.2, her preconceptions about the Moon phases are that the Earth blocks out the sunlight to the Moon which she believed causes the Moon phases.

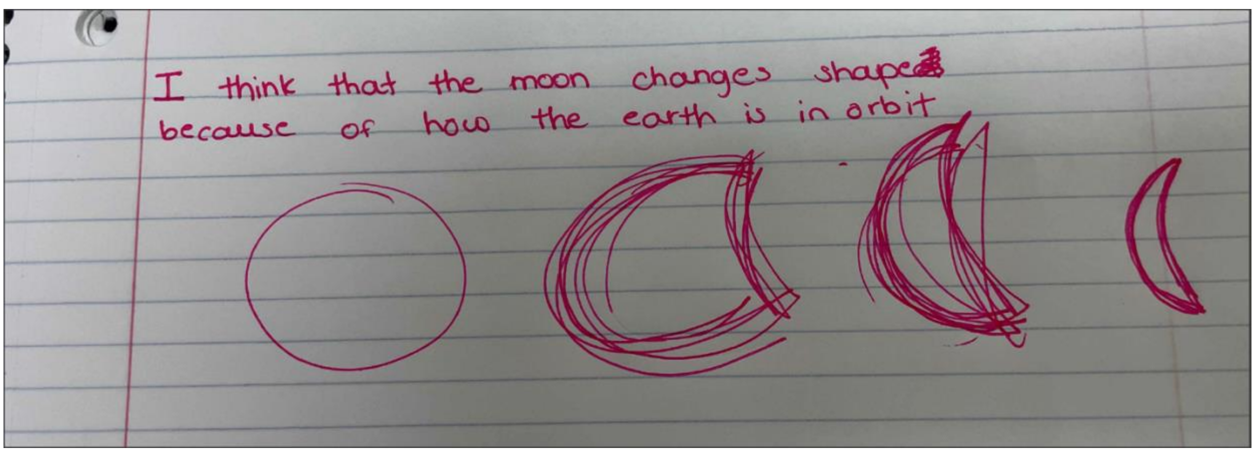

Figure 4.2. Madison’s quick drawing of the Moon phases showed a common misconception of the shadow on the Moon always being concave.

She described and drew a common misconception about the Moon phases [which incorrectly seems to show part of the Moon ‘blocked’ by a spherical object such as the Earth, especially because the gibbous phase would not have the shape she drew]. Her prior personal context showed that she was not familiar with at least the causes for the Moon phases and could not accurately draw the shape of the Moon during different phases even though she had been keeping a Moon journal as part of her methods course for two weeks. The Moon journal required the PSTs to draw the Moon every night for one month, ending with the planetarium experience on their last day of recording. Her work in Figure 4.2 showed that she was not fully correct about Moon phases, which was a commonality among the other PSTs. None were able to give a detailed correct description or drawings of the Moon phases and explain why they occur.

Physical Context of Learning in Planetarium Experience

During the planetarium experience, Madison did not actively participate in whole group discussions, which was not different from her behavior in her methods course. She remained in the back of the whole group discussion and did not answer whole group questions. But after the class split into small four-person groups to engage with the physical model [lamp for Sun, globe for Earth, Styrofoam ball for Moon] she was the first person in her group to grab the globe and offer a suggestion for how the Earth spins. She described in her interview that the planetarium experience helped her to see phenomena that she had never seen before such as the Moon's true shape during phases or the position of the Sun throughout the seasons. Her drawing in Figure 4.2 supports that she had not actually noticed the Moon's shape specifically in the gibbous phase before, but after the planetarium experience, she claimed that she started to notice the Sun and Moon in the real world.

> So, when we saw the Sun and then the Moon rising in the planetarium [that helped me as a science learner] because I don't notice them in the sky, like sure it

> probably changes or whatever. But after we left the planetarium, I noticed them in the sky. Like when it started to get cold, like fall and stuff the Sun was going lower. And I was like making the real-world connections out of [the visual model in the planetarium]. (Madison, interview)

She admitted that she had not paid much attention to the real-world phenomena of the Sun and Moon before but once she saw the fulldome visualization of the seasonal positions of the Sun and the shapes of the Moon during each phase, she realized this planetarium experience impacted her personal knowledge. Her personal context of learning shifted from her not noticing the Sun-Earth-Moon system previously to now noticing how this phenomenon can be experienced in her daily life for which she now has an explanation thanks to her planetarium experience.

Characterize Planetarium Experience Compared to Prior Personal Context

Madison's personal context of learning seemed to be centered on the need for hands-on learning for her own learning, and she hoped to use hands-on learning for her future students.

> The demonstrations with all the models [physical and visual] … allow students to be hands-on and actively participate in discovering the patterns between Earth, Moon & Sun … the [physical] modeling was very hands-on and I'm personally more of a hands-on learner. So if I'm just watching a video or something like that, like I'll enjoy it, but being able to actually physically do it, I thought that that was the most useful part [of the planetarium experience]. (Madison, interview)

Most of the answers she gave in her interview about the benefits of the planetarium centered around hands-on instruction as a sense-making tool for understanding phenomena. She discussed how she learned best hands-on and thinks most of her future students will learn best hands-on but briefly mentioned her apprehension to teaching differently for students beyond hands-on learning. “I think the most challenging for me, maybe just like reaching my students who aren’t as hands-on and active learners, whereas they’re more visual or are readers because that’s not how I learn.”

Madison also described how the planetarium helped show her how sociocultural learning could be beneficial for her future students :

> I think like as a teacher, you have to learn to work as a team and stuff. So being able to do that taught me how to work as a team, like I would with my like grade team, you know? And then also it shows like how [elementary] students will work as a team. So the [sociocultural learning in the planetarium] shows like the different aspects of both teaching and learning because what you’re going to do [as a teacher in professional learning groups] is what your kids are going to do in their groups. (Madison, interview)

Her reflection on her own work in a group developing the Sun-Earth-Moon model showed that she believed her future students would work similarly in groups if tasked to develop the same model. The physical modeling during the planetarium experience gave her a tangible activity to use in her classroom and the discussions we had around developing those models for students and the pitfalls that can be avoided, helped her to see how using a physical, hands-on model could work in her future classroom. Her group had multiple people manipulating the model, adding ideas, and adjusting their model, which could inform how she was drawing parallels for her future students when she will assign group work in her future classroom. She described the hands-on, phenomenon-based nature of science in her past as beneficial prior to coming to the planetarium, then she perceived the same style of sociocultural science learning that happened in the planetarium as beneficial to her for learning the content we addressed because it showed her how her students might interact together with the provided materials in small groups.

Finally, Madison reflected on the need to use informal learning resources like the planetarium so her students can experience things outside of the classroom first-hand.

> Something that is now very important for me is trying to get my students out and have real-life experiences, such as going on field trips like going to the science center or museums or farms and gardens, depending on what we are learning. I had those experiences growing up and I want to give those opportunities to my future students. (Madison, interview)

She reflected on her own experiences as a K-12 student and realized after the planetarium that these resources are still available for her to use to provide those life experiences and natural phenomena for her students. This new perspective of phenomenon-based instruction aligns well with NGSS instruction.

Summary of the Case

In the case of Madison, she described having many instances of quality science instruction in her K-12 experience, using hands-on activities which she wants to replicate for her future students. Her prior personal context included a previous understanding of the need for sense-making in the form of hands-on learning for quality science instruction. During the planetarium experience, she engaged more with the physical model in her small group than in whole-class discussions and had more control over her group's physical model. After the planetarium experience, Madison reinforced her judgment of the need for quality hands-on instruction that is student-centric. She told of her learning the importance of sociocultural learning within a collaborative classroom as needed in addition to hands-on modeling. She also now recognized the need for visual modeling and depicting real-world phenomena through visuals or taking students out of the classroom to gain their own life experience with the science content before moving into hands-on physical modeling for sense-making of the phenomenon. Her learning due to the planetarium experience seemed to be located between personal and sociocultural learning with a reinforcement for the physical learning that she had experienced.

John

Prior Personal Context

John was a very active PST in the science methods course and was often a leader when it came to instruction with his peers in the elementary classroom. He usually did not take the lead in planning the science lesson but in the clinical classroom, where several PSTs taught a short lesson as part of their methods course, he often took leadership in gaining students' attention, redirecting students' behavior, and discussing students' expectations. "Students are almost always well-behaved during instruction, especially when I am leading." The elementary students listened more quickly when he spoke, perhaps because he is a black man in a majority Black school, where research suggests Black elementary students perform better for Black male teachers (Easton-Brooks et al., 2010; Eddy & Easton-Brooks, 2011). There were also no black male teachers at this elementary school, which could have led students to pay more attention to him than his female peers because students in multiple different classes and in different grades responded to him similarly.

John was quick to talk first during methods class discussions offering his ideas, and inputs when they were learning science. He was not shy about putting himself out there with his hypotheses to the class when they were learning the science content and was not discouraged from participating even when he was wrong. John also shared his experiences in his placement and reflected on his teaching in more depth and more often than other PSTs based on classroom observations. John did not create a pre-video and in his interview did not discuss his prior experiences in science education as a student and opted to talk about the science instruction in his placement classroom.

Physical Context of Learning in Planetarium Experience

At the planetarium, his behavior seemed no different from the methods class. When we discussed at the beginning of the planetarium experience what the Moon is, he offered a potential idea and even though his idea was not correct he explained his reasoning.

> I think the Moon is a star. Because when I think of planets they have atmospheres. You can go into other planets but you can't go inside the Moon. We are walking on top of the surface here but inside of the Earth and you can't go inside the Moon, it has no atmosphere. (John, Planetarium Experience)

John's preconception that the Moon was a star seemed to be based on the idea that we have an atmosphere above us on the Earth, which he knew is a planet but the Moon is different due to no atmosphere and therefore must be a star. He held onto this idea that space only consisted of planets and stars and since the Moon did not fit his idea of a planet then it must be a star. Other PSTs did not challenge his perception but when I asked if they agreed no one answered.

John also asked questions throughout the planetarium experience, clarifying when he felt certain explanations did not match his lived experience. For example, when we discussed seasons he asked "Can you explain how it is supposed to be winter in some locations but it still feels hot sometimes? Like, Kentucky had 80-degree weather just this past January. How do you explain that?" He could have been projecting what he thought would be student questions because his final lesson plan was about climate change and how climate change affects students locally. He offered global warming as an answer to his own question so he seemed to be predicting his future students' pitfalls with equating weather to seasons.

During the planetarium experience, John was actively engaged throughout the experience, just as he was during the methods course. He volunteered first to read out the standard, the first to answer my first question of the day and most questions during the in-dome phase and led his small group during the physical model and lesson planning. When the PSTs started in their small groups on the physical model [lamp=Sun, globe=Earth, Styrofoam ball=Moon] with the task to show which way the Earth rotated, he was first to grab the globe and offer a suggestion for how the Earth rotated. He was active in his group when developing their model and asked his peers multiple times for their thoughts on what he was modeling.

In the group planned lesson for hypothetical future elementary students, he didn't have ideas for how to teach the lesson until his other group members started to develop the lesson. This is similar to his behavior in the methods class where when they co-planned their lessons, he would often not take the lead. He seemed to struggle with lesson planning in the methods class and during the planetarium experience.

"I want you to plan a series of lessons that would meet one of these standards for your target age range, what activities they are doing, what you would want your resources to show. Be specific. Do you think you can do it? –Breanna (planetarium instructor)

"No." -John

Prior to the planetarium experience he participated in the methods course planning by working in teams of around eight PSTs planning and teaching a lesson to elementary students in a clinical classroom, which could have provided him a chance to get by with others planning what he would do when he led the instruction. Once his other group members suggested they could start with the patterns like they had seen in the dome then he began to engage and added that if they could have VR headsets they could recreate their dome experience in the classroom. Once his group members offered more suggestions, he began to provide his thoughts on how to improve their lesson and added on to what the other group members were saying. By the end of the lesson planning his group had the most detailed plan (Figure 4.3) out of the other groups.

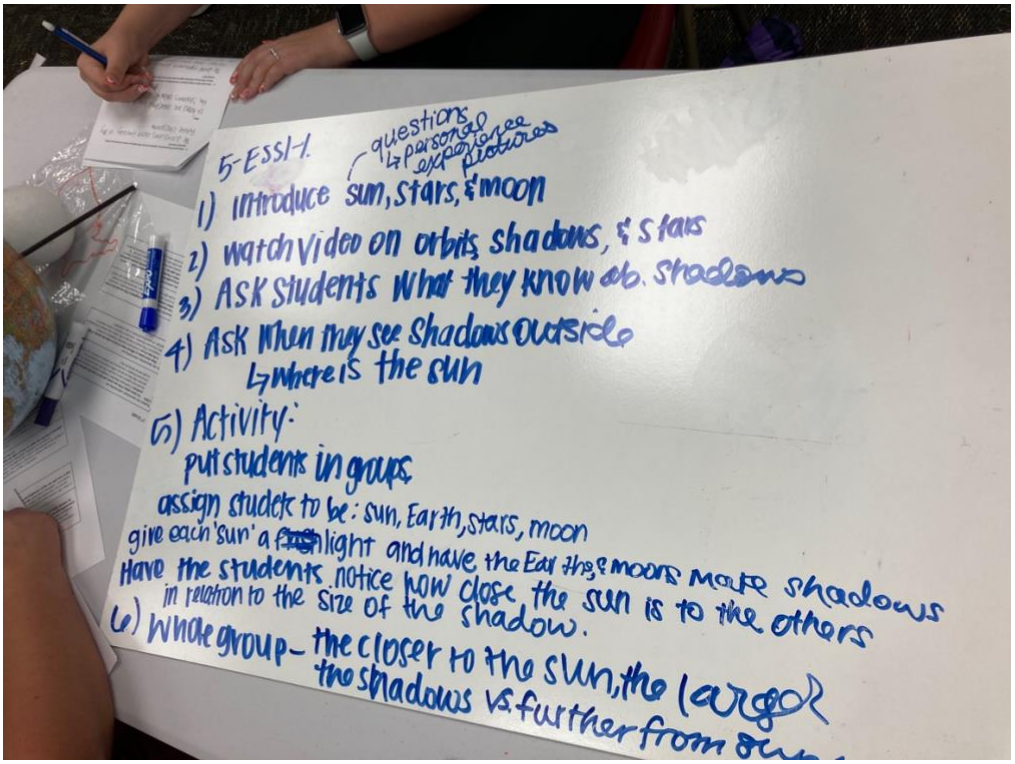

Figure 4.3. John's group-planned lesson to teach distance vs brightness of stars.

Characterize Planetarium Experience Compared to Prior Personal Context

After the planetarium experience, John described how the different phases of the planetarium experience combined helped him as a science learner. When asked to describe how the planetarium helped him envision his future teaching of science John said:

> I think since I learned best hands-on, I think [learning about] modeling [was most helpful] simply because I learned about the Moon phases in the past. But being able to actually physically see it and do it myself and like, so what would happen if we did this? Or what would it look like if we did that? Being able to physically model it, I feel like was really helpful, and I think that will also help the younger students that I'll be teaching. (John, interview)

John’s perceptions about the planetarium showed that the tangible demonstration of modeling was impactful to him as a sense-making tool and he saw the importance of modeling similarly for his future students. Beyond the physical modeling, he also saw the need to use multiple representations to help with the sense-making of phenomena.

> Not only was the [physical] modeling helpful for me, but also watching the video [the planetarium projections on the dome], because when I watched the video in the planetarium, where it actually showed the sunrise and sunset and showing the Moon phases. I got a visual idea of what it actually looks like. And then [physical modeling] we were able to use the lamps to kind of actually model what it looks like outside of Earth and why it looks like that when we see it from our [Earth-based] perspective. (John, interview)

He discussed the importance of multiple representations in modeling for his own science learning. Through multiple representations, he perceived that he now had a better understanding of the Sun/Earth/Moon system, and how to utilize sense-making as a tool to contextually make sense of natural phenomena.

John’s focus on the sociocultural context of learning emerged when he planned a lesson for future hypothetical elementary students with his group.

> I think collaboratively working in teams to come up with a lesson plan [was most useful]. Granted, we'll all be doing different grade levels and stuff, but it just kind of gave me a different perspective of how to plan things. I had my peers there that helped me kind of understand, and they remembered some of the things that I didn't remember from the [planetarium experience]. So being able to have time to

> practice making a lesson plan for younger students, I thought it was beneficial. (John, interview)

He discussed how his peers were pivotal in trying to plan a similar lesson because they could "bounce ideas off of each other". Lesson planning can feel isolating for PSTs in their individual classroom, but during the planetarium experience, the PSTs collaboratively worked towards the same goal. John said, "I feel like I normally would have to do this by myself".

Finally, John discussed the novelty effect of the planetarium and how the experience is unique and not replicable in the classroom but the out-of-dome physical modeling in combination with a planetarium experience could be beneficial to students.

> I think that while we can watch videos and stuff on YouTube, I really think the experience of being in a planetarium, such as having that large dome and looking at the sky and watching everything happen, and then being able to then go replicate that on their own? I feel like that would be most fascinating to them… I think [the planetarium experience] is definitely more engaging than the traditional ways of teaching children. (John, interview)

He understood that the physical context of being in the planetarium is a unique experience that could be utilized with his future students. The physical dome and materials the planetarium provided would be more beneficial for his students' learning than using traditional instruction. He also recognized the need for follow-up instruction using a different type of model for students' sense-making.

Summary of the Case

John was an active leader and participant both within his methods course and during the planetarium-enriched experience. His personal context before the planetarium showed he was a leader among his peers and was seen as a leader with elementary students. During the planetarium experience, he asked many questions to clear up any confusion he had and seemed to be asking a potential student question to get an answer to use himself as a future teacher. His reflections on the planetarium experience focused on the need for multiple representations in science instruction for students to visually see phenomena to base the instruction on and utilize hands-on physical modeling as a sense-making tool to describe the processes behind the natural phenomenon. He also described how the planetarium experience can't be replicated within the classroom but if students were to visit the planetarium and it was accompanied by in-class physical modeling it would be more engaging for students than the traditional method of instruction

John also discussed how the sociocultural nature of planning the group lesson was beneficial for him. He appeared to struggle with lesson planning throughout the methods course and during the planetarium experience until his group members took charge. Once they began to work collaboratively on the lesson in a small group, John became more engaged than he often was during his methods course planning. This could have been because he was only working in a group of three instead of in a group of 8 like in the methods course so he might have felt more pressure to participate in the smaller group. This pressure to lesson plan might have made him feel nervous as he did not feel he could do it, but once his peers took the lead he was able to offer more support.

Sydney

Prior Personal Context

Sydney was an active participant in her methods course, where she often took the lead in developing lessons, and was usually the first to speak when it came time for the PST groups to teach lessons in their assigned elementary classrooms. She often participated in whole group discussions in the methods course and she shared out in every class, her reflections on their lessons after they had taught. When asked to reflect on how Sydney had seen quality science instruction in her past she claimed, “So for me, I don't really remember doing science that much in school… and science is not allotted for a lot of time within the [placement] classroom I am in.” Her prior experience as a science student was apparently not memorable or did not leave any lasting impressions on her. During a pre-planetarium assignment, Sydney described how and why the Moon changes shape (Figure 4.4), but demonstrated a misconception of the Moon always being full and that it can appear to get much bigger. This further supported her description of limited science learning in her past.

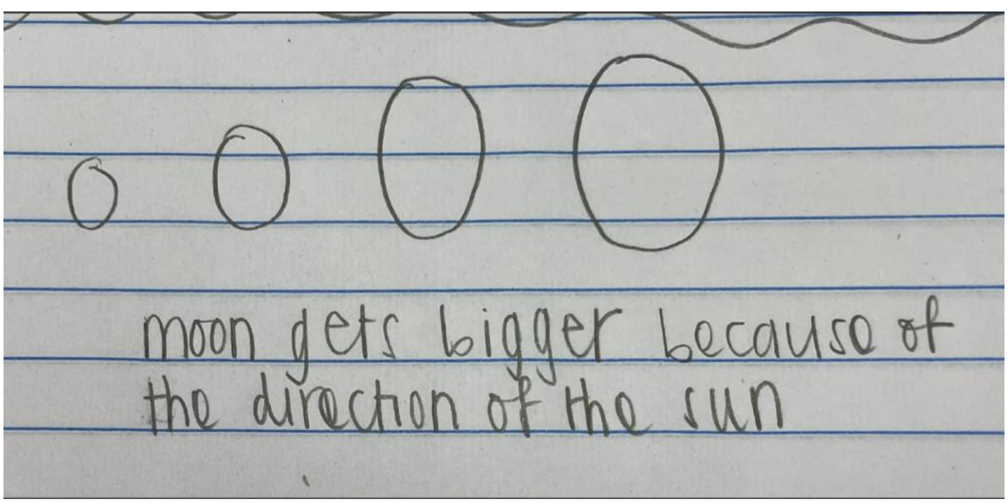

Figure 4.4: Sydney’s description of why the Moon changes shape

She then compared her lack of effective K-12 science experiences to how she is seeing effective science instruction now as part of the methods course and occasionally, but not regularly in her placement:

> Now that I'm seeing [science instruction in my program], I think something that's really beneficial for me to see is that it is more student self-directed learning. And I think that's super important, like allowing the student to have their own say-so in their learning and being able to explore on their own. (Sydney, interview)

Sydney saw the benefits of having student-centered learning with student-led explorations in her methods course. Her prior personal context of learning seems to be that she claimed to not have much of a science background but had begun to notice what she believed quality science instruction could look like and this type of instructional pedagogy is something to strive for in her own future classroom.

Before coming to the planetarium she reflected on her vision for her future science classroom:

> I want it to be student-led in my classroom and to scaffold instruction that doesn't explicitly tell the students the answers but I'll be able to guide them through it [the content]. Like [in the methods class] we had the paper and the book demo, where [Course Instructor] asked us which would fall fastest. Instead of telling us what would happen we got to make suggestions and see it happen for ourselves and using that [technique] will be beneficial for my students. (Sydney, pre-survey)

She was beginning to learn how to teach in a more student-centric way such as creating experiences and phenomena for her students to watch and explore, as she had been doing in the science methods course. Her values were already beginning to be NGSS-aligned with explicit pedagogical examples of student-centric instruction, whereas many of her peers did not talk about their future science classrooms in the same depth or specificity of NGSS-aligned instruction in their pre-surveys.

Physical Context of Learning in Planetarium

During the planetarium experience, Sydney engaged some in the physical model but relied on her peers to manipulate the model more than she did. This could be because she was not familiar with the science content (see Figure 4.4) as she had talked in her pre-video about not having much science experience during K-12. She was the first to agree that she needed the group to come back together at my suggestion with me scaffolding a little more of the model after I had noticed most groups, including hers, were not accurately modeling the Earth's orbit after 15 minutes. Then when the PSTs returned to their small groups to model the full Moon she repeatedly tried to put the Moon in between the Sun and Earth because it looked full from her perspective next to the Sun instead of from the perspective of John who was holding the Earth.

When planning the unit in her small group she participated as much as her peers but offered more specific suggestions for the lesson. For example, when her peers said they should ask preliminary questions to see what students know about the Sun whereas she suggested specific questions. For example, in a conversation with one of her peer PSTs; "Let's just ask background questions to see where they are and what they know."-PST #7 "Yeah, maybe we can ask, like, Does the Sun move? How do you know? What have you noticed about the Sun?"-Sydney. There were a few instances during this lesson-planning where a peer would offer a broad suggestion and Sydney would give a specific example, which could mean she was really attempting to plan a specific lesson she would eventually teach instead of providing generalities to a hypothetical lesson.

Characterize Planetarium Experience Compared to Prior Personal Context

Sydney's personal context of learning in the planetarium happened by learning content that she had prior misconceptions about. When discussing which part of the planetarium was helpful for her own science learning she said:

> I think the part in the planetarium where we actually got to visually see it [in the dome] because we came in as college students with a lot of misconceptions about where the Sun sets and rises, the Moon, and all that. So we were able to go ahead and address those and like, lay them all out on the table. So now we're prepared for that with our students in the future. I think whenever you had us like, stand around in a circle and we each like, got to participate in the model and see where exactly like the Earth was positioned and how it was tilted and so I think just that like instructional strategy, like making it a whole group [model] and being able to like talk about things and just hear everyone's ideas. And you didn't necessarily tell us, like, that's not right. You're like, "Well, what do you think?" or "How do you think about your model?" So I think being able to like, tell your students like you're not necessarily wrong but instead just giving them another way to look at things. (Sydney, interview)

Sydney believed the sociocultural context of learning that happened for her during the planetarium experience was most beneficial because she could discuss things with her peers and try to reason out how the model works without being directly told by the planetarium instructor exactly what to do or if their reasoning was right or wrong. She described the benefit of letting students work through their own misconceptions through purposeful guiding questions from the planetarium instructor who knew where the PST misconceptions and elementary student misconceptions would lie. She also described the benefit of having multiple representations; the visual model in the dome along with the PST-developed physical model, where everyone was participating and she would like to use these instructional strategies in her future classroom because she saw the benefit of both for addressing misconceptions for herself and her peers and how that would be useful for her future students.

Sydney further described the planetarium experience as helpful for her own learning as a future teacher of science:

> For my own learning, especially being in a teacher prep program right now, I feel like I'm being able to collaborate with my peers in planning a lesson. It was very beneficial because we're in [placement] schools this semester, so we take that knowledge and we were able to apply to what we were doing with our peers [in the planetarium experience] because we were also able to choose the grade band we want to [teach]. And so that kind of correlates with where we're at now, so we got to use that information [space-science content] and transfer it to a real-life example [lesson planning for space-science]. (Sydney, interview)

She perceived benefit from the sociocultural nature of the group lesson planning within the planetarium experience because she could take the content she just learned and transfer the knowledge immediately into group lesson planning for the age group she wanted to teach (K-2). She described the benefit of having this as part of the planetarium experience in this part of her educational journey now that the PSTs are in their first placement classrooms and are seeing how lessons get planned by their cooperating teachers. She may be beginning to feel the pressure of planning lessons on her own and potentially saw the value of doing that in a group of similar grade-band peers.

Sydney also described how the planetarium can be used for phenomenon-based instruction.

> So the planetarium can allow students to just like also have that observable factor like you don't have to necessarily tell them everything, they can look and they can notice and wonder for themselves. And that's how it becomes presented within discussions and conversations that are held [between planetarium instructor and students]. So just allowing them to like, explore for themselves, not telling them every single aspect or detail as soon as they come in and allow them to wonder and be like, "Wow, what is this?" And but not necessarily sitting down and saying, "This is what this is. This is what it is for." (Sydney, interview)

She perceived that students who came to the planetarium for a similar experience would benefit from seeing the phenomenon first and through guiding questions from a planetarium instructor could allow them to formulate their thoughts about the phenomenon and allow for sense-making to occur without direct transmission of instruction as can be typical in informal settings like during museum guided tours or produced planetarium shows.

Finally, Sydney described how her personal context of learning was most affected and she wished to provide the same type of opportunities for her students.

> I think the most important part [of the planetarium experience] to me that needed to be taken away [for my own learning] is being able to apply that information to

> what I and they [my future students] see in real-life experiences. So giving them the opportunity to explore those things and laugh and have fun and see it in a way that's relatable to them, but also being able to take that information and go home, maybe the next day and say, "Oh, I see the Sun is rising right now on my way to school" or something like that, and being able to notice that the Sun is setting as they probably get home from practice or something. So making connections between what they're learning in school and what is happening in the real world. (Sydney, interview)

Her learning within the planetarium experience can be framed as intersectional with all three aspects of learning; personal, for her to see the phenomenon, sociocultural, in exploring the phenomenon with her future students and physical, where the planetarium dome can recreate those lived experiences for her or her future students for them to reflect on in the real life.

Summary of the Case

Before the planetarium experience, Sydney could be described as motivated and reflective due to her constant and continued engagement in the methods course when planning lessons and reflecting on the mini-taught lessons. She described her previous science experience as unmemorable, but the methods course showed her new ways to teach science through showing (phenomenon-based) instead of telling. She expressed before the planetarium experience her goals for student-centric science instruction which can be considered NGSS-aligned pedagogy through guiding questions, and phenomenon-based instruction.

During the planetarium experience, Sydney displayed misconceptions about the Sun/Earth/Moon and recognized that she had those misconceptions. Her personal context perceptions about the planetarium experience focused beyond just her learning the science but her learning as a future science teacher. She described the helpfulness of seeing the phenomenon in the physical context of the dome and then modeling the phenomenon as a sense-making tool for understanding, which she hoped to use in her future classroom. She also described the sociocultural aspect of planning a lesson as beneficial for where she is in her PST program so she could work with other peers to develop grade-band-specific lessons together. She made connections from the planetarium experience and the several pedagogical methods used, to having an ideal student-centric, phenomenon-based science classroom for her future students.

Jessica

Prior Personal Context

Jessica was an active participant during the science learning portions of the science methods course. She seemed to answer more of the science content questions than other students. She was usually correct when she answered content questions asked by the course instructor, whereas many of her peers did not seem as comfortable with the science material as she was. When small groups implemented lessons she would ask the elementary students more questions in whole group discussions than the other PSTs likely because she was more familiar with the science content to know the answer. During the methods course, each week a few PSTs would present the material from a chapter reading of their course textbook, which was to include an activity, to the other

PSTs. Jessica was one of two teachers who presented by herself which could show she had more confidence in her ability to teach a lesson.

Before the planetarium experience, Jessica reflected on her vision for her future science classroom:

> One thing I want to do in my science classroom is using guiding questions. Normally in classrooms, a lot of the lessons are teacher-led and there's not a lot of prompting questions and the students just kind of sit there and absorb the knowledge. A lot of times it's not beneficial if the students don't relate to the content. I want my lessons to be student-led if at all possible. Of course, not all the time are students gonna be able to have physical, hands-on, or experience with the content. Like the Moon for example, they can't just go out and be able to see all the changes at once and everybody may have a different level of experience. We used to look in textbooks or dictionaries but now we have the Internet with so many resources. There's been a lot of virtual field trips that's been coming out that teachers have been creating for students that don't get to experience those topics right in front of them. I think it's best to use the models you have. So if the students don't get to do hands-on, then create something where they *are* able to explore it. (Jessica, pre-survey)

She described the importance of using guiding questions to have a student-centric classroom that guides students through active learning. She also recognized the need for hands-on activities for students but also recognized that not all content can be taught hands-on using the exact phenomenon in the content. She perceived that her future students may not all have real-world experience with all the science content and she would want to recreate that phenomenon for her students using models or other resources to give her students some first-hand experiences. Jessica's idealistic classroom is already being described in an NGSS-aligned way where she creates phenomenon-based instruction and uses models, virtual field trips, and online resources for sense-making when only hands-on activities may not be feasible. Many of her peers described in their pre-question using hands-on activities but she was the only one to talk about how hands-on experiences alone are not enough and cannot always be implemented for various reasons.

Jessica described her prior science experience as mixed between quality science instruction and completing workbooks:

> Um, I haven't seen a lot of science. Now, one of my favorite teachers in high school was a biology teacher, so I liked a lot of times she did like Kahoot quizzes and like little check-ins throughout. So that was one thing that was helpful to me. Other times, it just seemed like we were working out of notebooks. We were working out of books to plan for an experiment, and then you do the experiment for one or two days and it's done. (Jessica, interview)

Her experience with science instruction seemed mostly to be individual bookwork except for a Biology class in high school that had more interactive engagement. She did describe doing experiments but she felt the one-to-two-day labs could have been extended or could have happened more often. Although she felt she had limited dynamic science instruction she described her high school experience as being more interactive and hands-on compared to many of her peers' responses.

Physical Context of Learning in Planetarium

During the planetarium experience, Jessica was as active as she was in the methods course. She frequently answered questions or discussed her experiences and had taken the lead in her group to accurately model day/night, and then the direction of the Earth's spin on her first try. Her group members would wait and look for her answer and then would all agree with what she suggested or what she was doing. For example, when asked which direction the Earth should spin to make our whole-group physical model more accurate, she was the first to start spinning and was in the right direction. Other PSTs hesitated and then copied what she was doing.

Jessica also worked on the physical model on her own when I asked each group to model a different season to the rest of the groups. Everyone else was watching the other group model and she was manipulating the globe in her group to figure out how to model the season as well. She appeared to need to manipulate the model on her own as opposed to watching someone else model the phenomenon for her.

Jessica struggled along with her group to come up with a lesson for the 5th-grade standard 5-ESS1-1. They planned for students to look at their shadows in the sunlight to show the Earth's motion across the sky throughout a day. She asked me for help because she didn't feel their lesson was rigorous enough for 5th grade. I offered some suggestions of measuring their shadows' length and angle and potentially graphing their results to incorporate more math into their lesson, which she and her group immediately incorporated into their lesson.

Characterize Planetarium Experience Compared to Prior Personal Context

After the planetarium experience, Jessica was asked to reflect on how the planetarium was similar or different to her past science education experience:

> I'd say it's different. It was a lot more engaging and we were all like actively watching and answering and moving, like, even though we are college students like, I feel like I learned a lot more from that than I probably learned when I was doing the Moon phases or the Sun motion (in elementary school). (Jessica, interview)

The sociocultural learning as part of the planetarium experience was different for her than her prior experience. This quote described the collaborative nature of the activities as more engaging for her as a science learner because they were all involved in the modeling, where I had them moving around the Sun to demonstrate the year and rotating as the Earth rotates.

Jessica further described the benefits of the planetarium experience for herself as a science learner:

> Whenever we were inside the planetarium and the Sun was moving from east to west, I like that it showed the progression of like how it was lower during winter and higher during summer. So I technically had never really thought about that. Like, I knew that in winter you can't really see the Sun sometimes but it’s often because there are clouds or if it's snowing or if it's raining, you don't see it as much. But I hadn't ever really thought about the different levels of the Sun in the sky based on the season in like the length of days. Like now it's like 7:00 PM and

> it's pitch black outside (in October). I hadn't really thought about how that connected. (Jessica, interview)

She was able to see the visual model of how the Sun traveled throughout a day during each season as a connection to her lived experience that she did not have an explanation for. She made the real-world connection between the length of day and the height of the Sun in the sky as she saw in the visual model. She also described needing multiple representations of the Sun-Earth-Moon system for herself and by extension her future students:

> When you were showing us like the Sun, the Earth, and the Moon moving in the planetarium, like, I'm a physical learner, and I think that is a lot what I want to do with my teaching. So like the physical *and* visual stuff is really helpful. I want to be able to find videos or develop stuff like that since it was helpful for me and I want to use that in the future to teach my students. (Jessica, interview)

Jessica also discussed how the physical model helped her envision her future teaching of science:

> Also, like, me being able to do the physical demonstration, like with the foam ball and the globe that really showed me how I can be physical and walk around, show my students where everything's hitting based on the light. So I think that was probably the best part to imagine me teaching science because I get to like physically see how it is rather than just in the planetarium. It was helpful, but in the dome, they wouldn't be able to turn stuff [the physical model] on their own. They just get to see what's being presented in front of them. (Jessica, interview)

She perceived the physical model used as a sense-making tool was additionally beneficial after having visually seen the phenomenon of the Earth's spin and the Moon's phases. The visual model allowed her to see phenomena from an Earth-based perspective that she had not noticed before in her lived experience and the physical model helped to explain how this phenomena happens from a space-based perspective.

Jessica reflected on the planetarium experience and what she would want her future students to learn if they came to the planetarium for a similar experience:

> I would want them to take away that there is changes and you're going to gradually see them. So a lot of times we talked about how there is a full Moon and it may look like there's a full Moon for multiple days, but it's gradually changing if you look closely. So I think the planetarium did a good job of like showing that yes, it may look like it's in the same place in the sky every day, but it's different because it's a different day and it's in just a little bit of a different position so there aren't big changes day to day. (Jessica, interview)

She described how the planetarium showed the pattern of gradual change of the Moon's phases and she would want her students to see the same thing. The physical context of the planetarium allows students to create their own lived experience of the Moon's phases in an accelerated way.

Finally, Jessica described how the planetarium experience helped her to see science as a core subject area:

> I think that a lot of this [planetarium experience] will be beneficial because I didn't see the importance of science like I always thought of it like, all we did was already planned out experiments and all that everything those classes were based

> on in science, were just worked out of workbooks. But like getting to see what the students are able to do now, and like the planetarium, they get to do hands-on like we got to do hands-on. It was in small groups, so we each got to, like, test it out. And it wasn't just like, Oh, one person gets to do it and we all just watch a model. So I think that will be beneficial. (Jessica, interview)

She described how the planetarium gave her a tangible example of how to use hands-on learning in a way where all students can participate by using small groups. She also saw the benefit of having students develop their own model instead of handing students a "cookbook" lab, with written instructions explaining exactly what to do. She further added:

> I think there is a lot of things that you can do with science and like that Flipgrid like me going into teaching, I was like, "Oh, science is interchangeable with social studies" so I didn't really think of it as such a core content. But now I'm kind of realizing like, wow, science can be incorporated into math, it can be incorporated into reading. (Jessica, interview)

Jessica compared how she saw science as an "extra" subject instead of a core subject area like math or reading in her initial pre-question response but now, the planetarium experience showed her how science can be incorporated into these other main core content areas. Science can and should be seen as a core content area in elementary classrooms and she plans to incorporate it more fully in her future classroom.

Summary of the Case

Before the planetarium experience, Jessica appeared to be more prepared than her peers to be a teacher. She presented to the class alone for one assignment when almost all of her peers presented in groups. She engaged more with students in the clinical classroom by using guiding questions. Before coming to the planetarium, she also described that she wanted her classroom to be student-centric and she provided some explicit concrete examples of this including for example how she might use virtual field trips or locate videos on the internet to give her students some direct experiences with real-world phenomena. By contrast, her peers who expressed similar desires for a student-centric classroom typically did not have specific ideas for enacting that, instead expressing non-specific hands-on experiences as their primary instructional mechanism.

During the planetarium experience, she was still active when participating in the physical model and her group members let her take the lead during the modeling portion. She perceived benefit in the sociocultural nature of parts of the planetarium experience where she and her peers were collaborating to construct knowledge together. She also described the importance for her to experience multiple representations of models of the Sun/Earth/Moon system for her own learning and she plans to use this instructional strategy for her future students. Her learning and perceived benefits due to the planetarium experience happened within the intersection of sociocultural and physical learning, as she described how the physical space of the dome and the physical model as part of the planetarium experience helped her to learn the science content for herself and helped her to imagine doing something similar for her future students.

Cross-Case Analysis

A commonality between all five of the case teachers is that all five were active in the methods course. It is not a surprise that these five chose to do an interview because they were among the most active, responsive, and reflective of the PSTs in the class. The five case teachers had different levels of prior science experience, with Madison having the most robust background science experience in K-12 and Jessica mentioning some quality science experience. The other three case teachers had limited science backgrounds where they do not remember doing science or it was strictly bookwork. Prior to coming to the planetarium, there existed some expressed misconceptions about the Moon for three of the case teachers: Madison, John, and Sydney.

The pre-video had the 5 cases split, in what they discussed with Amber and Madison discussing the importance of hands-on experiences. Sydney and Jessica differed from this by talking more specifically about how they wanted a student-led classroom where they would try to use more guiding questions and provide more authentic experiences for their future students. John did not submit a pre-video.

During the planetarium experience, there existed a difference in engagement from engagement in the methods course. While John and Jessica remained as active as they had been in the course, they both appeared to slow down a little bit during the lesson planning until they were stimulated by their peers or me as their instructor. Madison remained reserved throughout both the methods course and the planetarium experience, which is consistent engagement in the two settings similar to John and Jessica although the degree of engagement differed. Although Madison did not engage much in whole-class discussions, she became very active while doing the hands-on model, which could be because she had experience with that kind of instruction. Amber and Sydney were more reserved than normal during the planetarium experience, which could be attributed to their stated lack of experience with science during K-12. Both Amber and Sydney became more engaged when it was time to plan a lesson, which was more similar to their behavior in the methods course when planning lessons. They both were very active and appeared to take the methods course and planning to be teachers more seriously by being specific in their plans and taking charge of the planning in their groups.

After the planetarium experience Amber, Madison, and John described the benefits of the physical model for themselves as science learners. Sydney and Jessica both said the visual representation in the dome was beneficial for their own understanding of the Sun-Earth-Moon system. This mirrors what most had described in their pre-videos. Amber and Madison discussed being hands-on learners and similarly found more benefit in the hands-on model during the planetarium experience. Sydney and Jessica talked about wanting to make real-world connections and experiences for their students and found the visual representations to be the most beneficial during the planetarium experience.

Four of the five cases discussed the importance of using multiple representations, either for their own learning or for their future students. They described how it was not one model that was more beneficial than the other but described the need for more than one model for their understanding and applied that to their future students. Multiple representations, these cases felt, were necessary for their future students' understanding, and they planned to use multiple representations within their classrooms.

Finally, three of the cases described the planetarium as an important resource that they would like to utilize. They also described how they would like to find similar resources in the community to inform the content they create. These cases saw the benefit of being in an informal environment and with an expert in the field, and they detailed a desire to bring this kind of experience to their students.

Aggregate of Remaining Participants

The second set of data analyzed was from the remaining eight PSTs who were also a part of this study but chose not to do an interview. These PSTs participated in the same planetarium-enriched experience and completed the pre-video and post-experience survey; their aggregate responses are described below.

Prior Personal Context

The remaining teachers' responses on the pre-survey echoed what the five case teachers discussed. Half of this remaining group of PSTs described using hands-on activities in their future classrooms. Similar to Amber, they were not more specific in answering why they wanted to use hands-on activities or how they reflect best practices. The vast majority also indicated that they planned to have a student-centric classroom where the class would be student-led, address all student questions/ideas, and use guiding questions. This also mirrors the responses of the five case teachers.

Physical Context

Hands-On Manipulatives

One of the main themes discussed in the post-experience surveys of most of these remaining PSTs was the benefit of the hands-on physical model using the lamp, globe, and Styrofoam ball to represent the Sun, Earth, and Moon respectively. Seven of the eight PSTs mentioned that the hands-on physical model was beneficial, either for their own learning or for use in their future classrooms. Three PSTs also mentioned that being able to develop and manipulate the model for themselves helped them learn better, and they plan to use the same technique with their future students. “I liked how we were in control of the models & were able to manipulate it ourselves & see how our manipulations made a difference" (PST #2). "I think our hands-on activity helped put abstract ideas into more manipulative and concrete ways of understanding. Students get to control the movement of the Earth & Moon & see how it works more concretely" (PST #8).

Planetarium Visual Model

Another major theme from the eight remaining PSTs that mirrored a theme from the five case teachers was the benefit of the physical context of the planetarium to show a visual representation of the Sun/Earth/Moon system on an immersive fulldome projection. five of the eight teachers believed the visual model was useful for their own learning. When asked what was most beneficial for their own learning, PST #7 said, "The portion showing where the Sun rises & sets during different seasons because I never really knew why the Sun set so early in the winter other than knowing we are on a axis. Now it makes alot more sense." The physical context of the dome visuals helped most of the PSTs by providing a more realistic visualization that mimics being outside, or in space and seeing the motions/orbits for themselves. Three of these five PSTs further described how this visual model helped them most to envision their future teaching of science: "Learning how to really explain and get my students understanding of orbits/rotating, etc. seeing it on the dome helped me to learn proper ways to teach/explain it. It [the visual model] helped me to better comprehend in order to share my understandings with others" -PST #5.

Six of the eight PSTs mentioned the planetarium was beneficial for more of a novelty effect for their students and as a resource. "I think they would enjoy the video being all around them. There is a lot of science material to learn and absorb. It [the planetarium] allows them to get a 3D experience" -PST #3. Another PST mentioned the benefits of using a fulldome: “It gave a more realistic video than a smart board” -PST #4. The physical context of using a fulldome planetarium can allow students to visualize things that would not be possible in a classroom.

Intersection of Physical Context with Personal Context

The post-experience survey prompted the PSTs to select specific parts of the planetarium experience that were listed for them in response to each of the four questions (see Appendix C). One unexpected result was that half of these PSTs did not select just one part of the planetarium experience as helpful for envisioning their future science classrooms. These four PSTs described the need for multiple representations of a phenomenon through modeling to be beneficial for their future student learning. “Today was really visual and hands-on, which is how I plan to teach science. Learning and experiencing this also allowed me to better understand the concepts because earth science is confusing to me” -PST #10.

These teachers described the importance of the learning at the planetarium being situated at an intersection between the physical context of the planetarium through the use of the dome and a physical model, with their personal context of learning as described above with PST #7. Other PSTs had also described where the planetarium was able to bring in their prior experiences (e.g., short days in winter, etc.) and turn those into phenomenon-based learning activities. “I think the scale of planets, Sun & stars is better understood in the planetarium than if it was shown in real life. Also, the ability to speed up time to see how seasons change and see the Sun’s position is beneficial for students w/o taking up months of time in the school year” -PST #8. A unique benefit to the planetarium is the ability to manipulate the model so students can see a full day happen in seconds and the change in the Sun's position throughout the year with just a turn of the knob. This PST described the benefit of using a planetarium to help decrease instructional time to achieve the same goal of experiencing the phenomenon of days or seasons.

Sociocultural Context

One distinction of the planetarium experience is the access to a professional in a specific field (astronomy) teaching an in-depth lesson that the expert had taught hundreds of times. The nature of planetarium work, and informal work at large, is the need for professional knowledge in a focused field and being able to demonstrate that knowledge repeatedly for many different population groups. As a result, the instructor in these settings becomes hyper-aware of potential student misconceptions simply due to the sheer number of times the lesson has been taught to hundreds of students at a time, and thousands of students per year.

I have been teaching the Sun/Earth/Moon system to thousands of elementary students per year for more than four years and have become very familiar with the mindset and knowledge base of elementary students. When I teach the PSTs at the planetarium, I bring a lot of my personal context of learning with me—a personal context that includes knowledge about the way elementary students think and the ways that students interact with the models I present. I presented to the PSTs first for them to engage in the model as a learner and many times throughout the lesson I engaged them as teachers with suggestions for how students will respond, potential misconceptions students will have, and potential ways students may build their own model. I provided real examples of student answers to questions and ways that I have navigated student responses, whether they are correct or incorrect.

Four of the eight PSTs explicitly mentioned that they found these conversations to be beneficial to them as future teachers of science. When asked what part of the planetarium was most useful for her future science instruction PST #1 said: “The discussion honestly. Hearing what you knew gave me a better idea of what/how to teach science to my students in the future…learning more of how students think and experience things. It’s good to know how they learn & how I can be open with them in teaching”.

Summary of the Aggregate Cases

The remaining participants’ responses on the post-experience survey mirrored many of the major themes and topics shared by the five interviewed cases and reported in more detail. The interviewed cases described the visualizations and/or the physical modeling as most beneficial for their own learning, which the remaining cases also identified. No new codes arose from the remaining cases. The lesson planning, discussions about their future teaching, and the physical model all arose as codes among the interviewed cases and this was also mirrored through the remaining cases, again with no new codes arising in their responses. Envisioning their future teaching, PSTs in both the interviews and remaining cases existed on a spectrum of parts of the experience being beneficial. Many felt the visuals were most beneficial as John described, others thought the physical model helped them by providing a tangible model they could take and use in their future classrooms, as Amber and Jessica described. Finally, all PSTs were in agreement that their future students would learn and enjoy the visualizations offered in the dome, with some describing the novelty of being in an immersive space or learning through experiencing the phenomena for themselves as if they were out in the world observing. Although there is less depth of insight from the aggregate of the remaining participants, the patterns of themes remain similar. This demonstrates that the five interviewed cases are typical PSTs among their class and that the themes extracted from the interviews can be applied to and echoed by the remaining aggregate cases with high probability.

CHAPTER 5: DISCUSSION

Below is a synthesis of all the data including the in-depth interviews from the five cases that serve as the critical source of evidence for pre-service teacher perceptions about the planetarium experience. This discussion is grounded in a synthesis across all pre-service teachers (PST). This section is organized by the research questions that guided this study and further by the conceptual framework underpinning this study. Following a discussion of the results are implications for similar planetarium experiences in pre-service teacher preparation programs and limitations of the study.

Purpose of the Study

This study aimed to answer the following research questions:

1. In what ways can a short planetarium-enriched learning experience within a science methods course shape the perceptions of pre-service teachers (PSTs) as science learners and as future teachers of science?
2. How can a short planetarium-enriched learning experience within a science methods course inform PST perspectives of science instruction aligned with the Next Generation Science Standards?

Pre-Service Teachers' Interrelationships Between Self as Learner and Self as Future Teacher

The planetarium experience was purposeful in engaging with the PSTs as science learners and as future science teachers. As the PSTs engaged in the planetarium experience, they were thinking metacognitively about their own learning and how this learning and the methods used to achieve that learning could be translated to their future classrooms and for their future students. All five case teachers discussed in their interviews specific aspects of the planetarium that they found helpful for themselves and related that those aspects should also be helpful for their students. There appears to exist an interrelationship between the PSTs as learners and the PSTs as future teachers. They reflected on how they believe they learned best whether through hands-on activities or through seeing phenomena visually at the planetarium, or both, and how the experiences could also be beneficial for their students. They were thinking about their own learning preference at the same time as thinking about their future students' thinking and preferences for learning. Then they were transferring the knowledge of the methods used in the planetarium experience and how that benefitted them as a learner to thinking about how they could use those methods (visual and physical representations) with their future students.

As the five case teachers discussed these interrelationships between themselves as learners and as future teachers, there were differences in which aspect of the planetarium they focused on as to what would translate to their future classrooms. For example, Amber described the visualizations in the dome as being the most helpful for her own learning and described how she now would like to use similar visualizations in her future classroom. Alternatively, Madison, John, and Jessica all described themselves as hands-on learners and how the physical model was helpful for them as science learners and thus thought the hands-on model would also be beneficial for their future students. Sydney described the benefits of using the physical model but instead of needing the physicality, she needed the sociocultural aspect of interacting with her peers and manipulating the model together. She could see the same method working for her students. While not all of the remaining aggregate cases described these interrelationships in their post-survey, neither did the five cases when analyzing only their written post-surveys, but maybe if the other PSTs had been interviewed they might have discussed the interrelationships between themselves as science learners and as future teachers as well.

Pre-service Teacher Perceptions of Themselves as Science Learners

This section focuses on research question one to discuss PST perceptions of the benefit of the planetarium for themselves as science learners. As discussed in Chapter 2, PSTs are often learning science themselves within their methods course as they are also learning how to become teachers of science. They also are at a critical point of evaluating their past K-12 experiences in science, which can lead to reflection on typical practices and what practices they will utilize in their own classrooms. The goal was to create effective teachers by creating reflective teachers (Zeichner & Liston, 2013). The upcoming sections are organized by the conceptual framework that underpins this study, the Contextual Model for Learning (see Figure 1.2).

Personal Context for Learning

Most PSTs identified the visual model in the planetarium dome as helpful for themselves as science learners because they could witness the patterns of change in the Sun/Earth/Moon system quickly. They noted that the planetarium dome and software can speed time up as an effective way to facilitate opportunities to notice patterns as opposed to waiting for these patterns to happen in real time. For example, chapter 4 offered evidence that Jessica described the visual model of the planetarium dome displaying the height of the Sun in the sky during different times of the year as a learning model for her to realize how the height of the Sun corresponds to the length of the day and how this affects seasonal weather.

Half of the PSTs also identified the physical model where they manipulated the physical globe around the lamp (Sun) as helpful for their own learning. Many described how being able to manipulate the model themselves instead of just being shown a model by the instructor helped them to better understand how the phenomena of sunrise/sunset, Moon phases, and seasons work. For example, John described in his interview, and many of his peers talked similarly, about how they feel they learn best when using a hands-on model. Many of the PSTs described in their pre-survey that they plan to use hands-on models in their future classrooms, which could be because they feel they learn best from hands-on activity with physical models and so will their students. Their reflections on post-planetarium experience seemed to confirm for many of them that well-designed physical models can be an effective learning approach.

Physical Context for Learning

The planetarium experience as a whole takes place within a unique physical context for learning. PSTs were outside of their regular elementary science methods classroom and in a planetarium with access to different materials from those normally used in their methods class. Much of the learning the PSTs described as beneficial for their own science learning was framed within the physical context of learning. They found the planetarium visuals and manipulatives supported their learning about the Sun/Earth/Moon system. During the interviews, the PSTs provided specific insights into the value of this physical context by describing the 360-degree nature of the dome and its capabilities to demonstrate many days and months within a few seconds as critical in understanding the content. They also described that they needed the space within the lab to be able to manipulate the model on their own; almost all described themselves as hands-on learners. Interestingly, many described that their personal context of learning needed to be hands-on but then described the visualizations in the dome as also beneficial to their own understandings.

Pre-service Teacher Perceptions as Future Science Teachers

Interaction of Learning Contexts

PSTs identified which parts of the planetarium experience helped them to envision their future teaching of science in their classrooms and which parts were most useful to their future science instruction. Many chose to go outside of the options listed on the survey and instead emphasized the combined value of several features of the experience. Half of the PSTs explicitly said that they appreciated the multiple representations used during the experience and described needing to use both the visual and physical representations regarding their future teaching. The PSTs described how both types of models—visual models in the dome and physical models with manipulatives in the lab —helped them to learn better and helped them to envision how they would like to teach in their future classrooms.

The multiple representations they experienced in the planetarium are at the intersection of physical, personal, and sociocultural contexts. The physical model provided a collaborative learning opportunity for PSTs to interact together to build a model with their peers. The visual model included intentional interactions through planned questioning and discussion with the instructor and also left opportunities for PSTs to ask questions to the instructor. The time allotted for planning a similar lesson for future elementary students allowed PSTs to once again work in small groups to brainstorm together how they would break down the content they learned at a more complicated level to one more appropriate for their younger future students. The findings of this study showed these three parts of the planetarium experience affected them in a personal way by helping them to both understand the content better for themselves and to conceptualize how their students might engage with this content in the future.

Physical Learning Context

The physical modeling within the planetarium experience was explicitly identified as being most helpful for future science instruction by seven of the 13 PSTs. Many of the PSTs described how the physical model helped them to learn and thus would help their students learn through active participation with the model. The abstract science ideas they explored were processed using manipulatives to make the learning more concrete for themselves, and they believed they would do something similar for their students. None of the PSTs described the visual model within the dome as helpful to envision their future science instruction, likely due to them not having a planetarium in their classroom to utilize, so they may be thinking about specific things they can do within their own classrooms. However, five PSTs said they would want to bring their students to the planetarium so their students could experience the same visual modeling.

Sociocultural Learning Context

The sociocultural learning context was enacted in the planetarium experience through group discussions about teaching in their future classrooms, small group work on the physical model, and small group work planning a lesson. The findings showed that some PSTs found the discussions about teaching in their future classrooms to be the most helpful for their future science instruction. The social aspect of the “teacher talk” that happened throughout the experience focused on discussing what students might think or how students might respond to questions the instructor asked the PSTs and asked the PSTs to reposition their thinking from the perspective of hypothetical future elementary students and what they might say. These interactions helped the PSTs to have a better idea of what to expect from their future students.

The lesson planning also required the PSTs to work in small groups to plan a lesson together for either future K-2 students or grade 3-5 students. A few teachers also described planning the lesson with their peers as the most beneficial for their future science instruction, because they could hear what their peers knew or offer suggestions and build on each other’s work. The PSTs may think, as John described in his interview, that planning is often done in isolation and he believed it was a good thing to have his peers to rely on for planning a lesson and to utilize what they may know.

Pre-service Teacher Perceptions About Their Future Students

The post-experience survey specifically included a question about their beliefs about future students within the planetarium even though the other questions could have been answered without students in mind. Most PSTs discussed their future students outside of this question, but responses to this specific question showed that they believe the planetarium itself would help students learn. Nine of 13 PSTs described the importance of the visual model on student understanding. They believed the immersive, fulldome visualizations are necessary for students to see real-world phenomena quickly which cannot be replicated in the traditional classroom. Madison, John, and Sydney highlighted how they wanted their students to experience the novelty of going to a planetarium and being immersed, and feeling like they are actually in space. They described how they would like to use the planetarium as a resource and now they know there are other resources like a planetarium that can be utilized in their classroom. Jessica focused on the specifics of using the same visualizations she experienced to teach her students about day/night and seasons and using those visualizations to teach her students about those patterns in the sky.

Pre-Service Teacher Perspectives of Science Instruction Aligned with NGSS

The planetarium experience was designed to provide a specific example to PSTs of NGSS-aligned instruction, with an explicit focus on the three dimensions: the Crosscutting Concept of Patterns, the Science and Engineering Practice of Modeling, through the Disciplinary Core Idea of Earth and Space Science by using phenomenon-based instruction and sense-making as a tool for interpretation. At the beginning of the experience, I reviewed the progressions for elementary students with modeling and patterns to show what their students need to be able to do to meet the performance expectations from the NGSS. The findings showed that no PST mentioned this part of the planetarium experience as helpful for them. This may be because they are typical of elementary PSTs in that they have little science experience (as many described in their pre-surveys) and may be more concerned with just learning the science for themselves and learning how to manage a classroom as opposed to the much more difficult task of careful consideration of the progressions of learning and how to craft student experiences to advance them along these progressions. NGSS requires teachers to seamlessly integrate the three dimensions through a phenomenon-driven sensemaking lens, which is a complex and rigorous task, especially for new elementary teachers (McFadden, 2019; de los Santos, 2017).

Phenomenon-Based Instruction

In their pre-survey responses, the PSTs discussed their initial visions of their future classroom. Many discussed how they wanted their classrooms to be student-led but had somewhat naïve ideas about what that might look like. For example, Amber described her future classroom as having no direct instruction. Many talked about using hands-on activities but did not expand on what this could mean or why it was necessary. Also, half of them described that they wanted students to see that science is everywhere and is important to their everyday lives. There existed some evidence of initial ideas of NGSS-aligned instruction before the PSTs came to the planetarium, but most only said their classroom would be student-led without details of what that means or how it looks in a classroom. Below details the themes of PST perceptions from the results as they relate to phenomenon-based instruction.

Modeling.

After the planetarium experience, most of the PSTs described the importance of modeling in some way for their students, either through physical modeling or visual modeling. More concretely, they described a desire to replicate what was done during the planetarium experience in their classroom, by finding video resources similar to what was shown on the dome or taking the hands-on model we developed and doing something similar in their classroom. This shows that the PSTs walked away from the experience with a more concrete idea of what modeling is, why it is important for student learning, and how they can model in their classrooms. Modeling can be framed within a context of students thinking about the real world, which allows for modeling to be utilized as phenomenon-based instruction. The teachers described how using models to create phenomenon-based experiences was necessary when certain content cannot be replicated in the classroom such as the space-based perspective of the hands-on modeling.

Patterns.

The results indicated that the PSTs found they needed to see the patterns of the Sun-Earth-Moon system for themselves as learners of science. They described how seeing the patterns in the dome allowed them to see the phenomena for themselves. Many also described how they had not noticed those patterns themselves previously, such as when Madison described not noticing the height of the Sun in different seasons, or they had not thought about the phenomenon and the mechanism behind the phenomenon. The PSTs also highlighted the importance of showing the patterns to their students so they could also experience them first-hand, especially since students may not have noticed the Moon phases changing or the position of the Sun throughout the day or year. The planetarium provided a space to experience these patterns without having to wait for them to occur naturally, which many of the PSTs described as a benefit to having a resource like the planetarium.

Sensemaking

There were a few instances within the results that showed there were shifts in PSTs' perspectives and understandings of NGSS-aligned instruction. Many described the benefits of the visual model in showing real-world phenomena and the importance of having that phenomenon-based instruction for them to witness the phenomena first-hand, and this was pivotal to their understanding of the mechanisms behind the patterns they were seeing. All five cases detailed how the physical model was useful for them as a sense-making tool and how they hope to utilize this method in their future classrooms. Most all PSTs could see how being able to manipulate their own model to make sense of phenomena was needed for them to understand how their manipulations affected the model. Their ability to adjust the model on their own could help to immediately answer their what-ifs without relying on asking a peer or instructor to do it for them.

Importance of a Knowledgeable Instructor

The results demonstrated that the teachers perceived the planetarium experience to be successful in helping them as science learners and as future teachers of science. Many of the PSTs described the discussions and advice from me as critical to their understanding of the science material and their future students. There appears to be an importance for an informal educational program to have an informal educator who has more than just the knowledge of the content, but also knows the intricacies of NGSS, and knows the pedagogy of and experience with teaching science to elementary students. Having a planetarium be a part of a methods course, on its own will not necessarily have similar impacts because most planetarium educators do not have K-12 experience or a teaching degree. The benefits of this planetarium experience are likely in part due to the instructor knowing the content and having experience teaching that content to thousands of elementary students, which provided a unique opportunity for the PSTs to learn from a knowledgeable instructor of science, and science pedagogy.

Limitations

The limitations of this study are that this study only existed as part of one science methods course within one university. More research is needed to see if similar results happen across different instructors or different universities. Also, the PSTs may not yet have a fully developed their reflection abilities for the complex task of teaching potentially because all the PSTs were young and at the beginning of their journey to become teachers. Therefore, it is possible that there may be blind spots they themselves may not realize. I was also not able to observe the PSTs teaching science to know whether their perceptions aligned with their goals for science instruction. The main goal of this study was to explore the possible impacts of a time-restricted planetarium experience that would align with, without too much disruption, into a standard science methods course. So while this was an intentional part of the research design based on practicality, it is also a limitation in that the experience was necessarily brief in the context of seeking meaningful, complex change in PSTs. While there existed a harmony in responses between the five interviewed cases and eight aggregated cases, more research is needed to analyze a greater number of elementary PSTs across different cohorts and in different universities.

Implications

The planetarium experience at the core of this study is one example of a program offered by a planetarium specifically to elementary PSTs with a focus on NGSS-aligned instruction. This research demonstrated the importance of this planetarium experience on PSTs' science learning, learning as future science teachers, and shifts towards NGSS-aligned instruction.

Elementary Science Methods Instructors for Pre-Service Teachers

Elementary pre-service teacher prep programs have a large amount of content to cover, including the science topics, and how to teach those topics to a range of elementary students of different abilities, statuses, etc. (Appleton, 2006; Santau et al., 2014). Often all of the science content and methods are, and as is the case in this study, taught within one class for one semester. Science methods instructors need to be strategic in what they choose to teach to ensure their classes are as effective as possible. The planetarium experience in this study is arguably justified in being included as one week of instruction in a methods course because of the benefits to PST learning as students, as future teachers of science, and as an example of NGSS-aligned instruction. The value of the planetarium experience is that it was effective for PST learning of new science ideas for themselves, which leads to more specific and concrete ideas for how to teach future students and why that might be effective based on their own learning experience. The planetarium experience focused on the recognition and appreciation for the value of NGSS-aligned emphases on phenomena/phenomenon-based instruction, the Science and Engineering Practice of modeling, the Crosscutting Concept of patterns, and sense-making.

PSTs detailed the benefit of experiencing multiple representations throughout the experience for their own learning and described the importance of doing the same for their future students. The discussions had throughout the experience allowed for the PSTs to talk with a more seasoned expert in teaching these space science standards to elementary students. They perceived benefit from discussing common misconceptions and potential student ideas, and reactions to the models. They also detailed the benefit of having a more knowledgeable other to teach them about potential adjustments or pitfalls in their planned lessons. Finally, they believed working together with their peers was beneficial for their learning by building models and planning the lessons together. The combination of all parts of the planetarium experience engaged the teachers in all contexts of learning (physical, personal, sociocultural) which could be why the PSTs found benefits in all aspects of learning and saw how this type of instruction could impact their future students.

Planetariums and Planetarium Educators

This study contributed to the larger research base about the benefits of planetariums on learning and specifically PST learning. The results revealed how a well-structured, well-planned planetarium experience by an instructor knowledgeable about the science, NGSS, and pedagogy, caused PSTs to learn more about the Earth and Space Science content by experiencing the visual model of the Sun-Earth-Moon system within the planetarium that many felt could not be replicated in a traditional classroom.

The findings of this study indicated the importance of having a knowledgeable instructor for teaching PSTs, where the instructor has knowledge of the content as well as experience with teaching the content to elementary students. The PSTs as part of this study described the benefit of the interactions with a more knowledgeable instructor for their own learning as a future teacher of science. For example, the planetarium instructor guided them through how students would interact with certain models and addressed misconceptions their future students would have with the specific content taught. It is unlikely that such an experience without such a knowledgeable instructor will generate similar positive results.

Conclusions

The planetarium experience presented the inner-workings of the Sun-Earth-Moon system to elementary PSTs by using a visual model within the dome and a hands-on model outside of the dome. Some PSTs learned the content because of the visualizations in the dome, and some learned through the use of the hands-on modeling outside of the dome. There also existed some PSTs who described needing multiple representations (both the visual model and physical model) as needed for their own learning of the Sun-Earth-Moon system.

The PSTs also described how the planetarium experience helped them as future teachers of science. Many of the PSTs found the tangible example of the hands-on model as important for their learning as a future science teacher because the model could be used within their future classrooms, and served as an example for how their students might engage in similar models. Also, the discussions centered around the models used within the planetarium experience provided the PSTs with insight into their future students' behaviors with modeling, and prior knowledge of the content.

This experience served as a context-rich example of key NGSS features, but arguably PSTs may have difficulty translating those specific experiences to place similar value on different practices and other Crosscutting Concepts. It may be helpful to further support PSTs to at least consider the value of all Practices and Concepts even if they don't have time to have direct experiences with each of them. While one might hope that the PSTs are able to extend the value of these planetarium experiences to other aspects and topics of their future science teaching, this study did not explicitly document if or how any of these benefits might be transferable.

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Appendix A

Modeling Progressions in Elementary Grades

Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices
Developing and Using Models A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. Modeling tools are used to develop questions, predictions and explanations; analyze and identify flaws in systems; and communicate ideas. Models are used to build and revise scientific explanations and proposed engineered systems. Measurements and observations are used to revise models and designs.	Modeling in K–2 builds on prior experiences and progresses to include using and developing models (i.e., diagram, drawing, physical replica, diorama, dramatization, or storyboard) that represent concrete events or design solutions.	Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions.
	• Distinguish between a model and the actual object, process, and/or events the model represents. • Compare models to identify common features and differences.	• Identify limitations of models.
	• Develop and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed world(s).	• Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events. • Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution. • Develop and/or use models to describe and/or predict phenomena.

Retrieved from NGSS appendices (2013).

Appendix B

Patterns Progressions in Elementary Grades

Progression Across the Grades	Performance Expectation from the NGSS
In grades K-2, children recognize that patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence.	1-ESS1-1. Use observations of the sun, moon, and stars to describe patterns that can be predicted.
In grades 3-5, students identify similarities and differences in order to sort and classify natural objects and designed products. They identify patterns related to time, including simple rates of change and cycles, and to use these patterns to make predictions.	4-PS4-1. Develop a model of waves to describe patterns in terms of amplitude and wavelength and that waves can cause objects to move.

Retrieved from NGSS appendices (2013)

Appendix C

Post-Experience Evaluation

During today's class at the planetarium you experienced the following:

- Review of the progressions of modeling and patterns for elementary students
- A short segment of the planetarium show Perfect Little Planet
- Discussions about teaching in your future classroom (at different times throughout class)
- The immersive visual model of the Sun and Moon in the planetarium dome
- Physical modeling of the Sun, Earth and Moon with the lamp, globe and Styrofoam ball

1. Which part of the planetarium experience did you find most interesting for your own learning?

   Why?

2. Which part do you find most useful for your future science instruction?

   Why?

3. Which part of the planetarium experience do you think helps you most to envision your future teaching of science?

   Why?

4. If you were able to bring students to the planetarium, what do you think they might enjoy the most or what do you think they might be able to learn that they wouldn't necessarily without coming here?

Appendix D

Post-Interviews

1. Which part of the planetarium experience did you find most interesting for your own learning?

2. Which part do you find most useful for your future science instruction?

3. Which part of the planetarium experience do you think helps you most to envision your future teaching of science?

4. If you were able to bring students to the planetarium, what do you think they might enjoy the most or what do you think they might be able to learn that they wouldn't necessarily without coming here?

5. How have you seen effective science instruction modeled before?

6. Compare how the planetarium experience was similar or different from effective science instruction you have seen in the past. Can you give an example?

7. In what ways, if any, has the planetarium experience changed or added to your vision of strong science instruction?

8. When thinking about your future students and considering some of the teaching ideas we explored in the planetarium, what do you anticipate being the most challenging for you in terms of helping your students acquire understandings of science that you intend for them?

9. What final reactions and reflections would you like to share about the value of the planetarium experience in your development as a future teacher of science?

CURRICULUM VITAE

Breanna Graven (Ausbrooks)

EDUCATION

2024	**Ph.D., Curriculum and Instruction | University of Louisville, Louisville, Kentucky** Dissertation: *Using a Planetarium to Support Pre-service Elementary Teachers' Development of Three Dimensional Science Teaching* Dissertation Committee: Thomas Tretter, U of L, Department of Elementary, Middle, & Secondary Teacher Education, Director, Center for Research in Mathematics and Science Teacher Development; Sherri Brown, U of L, Department of Elementary, Middle, & Secondary Teacher Education; Sheron Mark, U of L, Department of Elementary, Middle, & Secondary Teacher Education; Justin McFadden, U of L, Department of Elementary, Middle, & Secondary Teacher Education; Sue Peters, U of L, Department of Elementary, Middle, & Secondary Teacher Education
2017	**M.A.T., Middle School Science and High School Physics |** University of Louisville, Louisville, Kentucky
2015	**B.S. Physics w/ Emphasis in Astrophysics |** University of Louisville, Louisville, Kentucky

INITIAL KENTUCKY TEACHING CERTIFICATIONS

Grades 6-9: Science
Grades 9-12: Physics

PROFESSIONAL EXPERIENCE

2022-Present	**Graduate Research Assistant |** University of Louisville, Louisville, KY | Speed School of Engineering, Advisor: Pat Ralston
2016-2022	**Planetarium Educator |** Gheens Science Hall and Rauch Planetarium, University of Louisville, Louisville, Kentucky

2016-2021 **Graduate Teaching Assistant |** University of Louisville, Louisville, KY| College of Education and Human Development, Advisor: Dr. Tom Tretter

2013-2016 **Research Assistant |** University of Louisville, Louisville, KY | Department of Physics and Astronomy, Advisor: Dr. John Kielkopf

2014-2015 **Undergraduate Teaching Assistant |** University of Louisville, Louisville, KY | Department of Physics and Astronomy, Advisors: Dr. Ray Chastain and Dr. John Kielkopf

2009-2015 **Planetarium Operator and Student Worker |** University of Louisville, Louisville, KY | Director: Rachel Connelly and Tom Tretter

GRANTS AND GIFTS

2019 Astronomy Modeling Workshop for High School Teachers. Co-PI. NASA-Kentucky enhanced mini-grant. $25,000.

AWARDS AND ACTIVITIES

2018 Developed the Mary Ann Russell Science Education Exhibit| Gheens Science Hall and Rauch Planetarium, Louisville, KY

2017 Outstanding Student Achievement in High School Science Education | University of Louisville College of Education and Human Development, Louisville, KY

2017 Developed with a team the William G. Russell Meteorite Collection Exhibit | Gheens Science Hall and Rauch Planetarium, Louisville, KY

2014 William Marshall Bullitt Award in Astronomy | University of Louisville Department of Physics and Astronomy, Louisville, KY

2010-2019 Society of Physics Student- Member | University of Louisville Department of Physics and Astronomy, Louisville, KY

2009-Present Honorable Order of Kentucky Colonels-Member

2009 Girl Scout Gold Award | Girl Scouts of Kentuckiana| Bowling Green, KY

INVITED PRESENTATIONS

Ausbrooks, B., & Heilers, T. (2018, November) *Stellar Cartography: An Astrophysicists Guide to the Planetary Systems in Star Trek*. Invited presentation at Louisville SuperCon.

Ausbrooks, B., & Mills, B. (2018, March) *Experiences of Women in Astronomy*. Public presentation in planetarium for the week-long lecture series on the empowerment of women in space science, Louisville, KY.

Ausbrooks, B., (2017, June) *A Tour of the Universe.* Invited presentation at inaugural Our Place in Space public conference, Louisville, KY.

Ausbrooks, B., Aebersold, J., & Richter, N. (2015, October) *Pathways for Girls in STEM.* Invited presentation for annual Girl Scout STEM Initiative, Louisville, KY.

CONFERENCE PRESENTATIONS

Graven, B., & Ralston, P. A., & Tretter, T. (2023, June), *First-year Engineering Students' Sense of Belonging: Impact of COVID-19 and Efficacy as a Predictor of Graduation* Paper presented at 2023 ASEE Annual Conference & Exposition, Baltimore, Maryland. https://peer.asee.org/43716

Tretter, T., & Nasraoui, O., & Spurlock, K. D., & Graven, B. (2023, June), *Board 313: Implementing Computational Thinking Strategies across the Middle/High Science Curriculum* Paper presented at 2023 ASEE Annual Conference & Exposition, Baltimore, Maryland. https://peer.asee.org/42871

Pendleton, A., & Ausbrooks, B. (2020, March) *High-Yield Routines for Eliciting Student Thinking in Mathematics and Science Classrooms.* Presentation at the 2020 Kentucky Center for Mathematics Conference, Lexington, KY.

Ausbrooks, B., & Tretter, T. (2019, September) *Efficacy of an Astronomy Modeling Workshop on Teacher Learning.* Presentation at 2019 Mid-Atlantic ASTE Regional Conference, Pipestem, WV.

PUBLICATIONS

Graven, B., & Ralston, P. A., & Tretter, T. (2024) *Validity Evidence for Parsimonious Sense of Belonging Scales for Engineering Students*. Journal of Engineering Education.

PENDING PUBLICATIONS

Howlerda, B., Chastain, R., Johnson, D., Ausbrooks, B. (under review) *Gender Differences in Participation and Outcomes in Astro 101 Classes.* Astronomy Education Journal