Abstract

The dissertation presents a new approach for the study of preservice elementary teacher astronomy education. The approach suggests that learning astronomical concepts are facilitated by greater sophistication in scale perception and spatial-aptitude. This dissertation is underscored by the national call for elementary science education reform efforts and suggests certain strategies shown more effective for the development of accurate astronomical comprehension.

The present research study describes how preservice elementary teachers conceptualize and communicate ideas about Space. Instead of assuming a universal mental conception of cosmic orientations and relationships, the dissertation claims that the perception of Space related dimensions vary among preservice elementary teachers. Furthermore, the dissertation suggests individual perceptions of the scale sizes and orientations of celestial systems have direct influences on mental models used to organize and communicate astronomical information. The development of inaccurate mental models of the scaled dimensions of Space may perpetuate the teacher-student cycle of misconception and naïve-theory generation among children in elementary education settings.

The ability to conceptualize the vast cosmos is facilitated by the minds ability to think about vast scales and orientations of celestial objects. The Earth-based perspective of astronomy education compels the learner to think about astronomical principles within imaginary frames of reference and across unfamiliar scaled dimensions. Therefore, mental astronomical model building is underscored by the perception of scale and cosmic spatiality. This study suggests these cognitive skill sets are interconnected and facilitate the learning of accurate astronomy principles; as well as play an important role when designing an astronomy education program for preservice elementary teachers. This research study is comprised of three separate standalone
articles designed and formatted for journal submission. Chapter 1 outlines the intent, rationale, and design of the overall dissertation process and format. Chapter 2 describes an in-depth review of the specific astronomy curricula used for comparison by subsequent chapters and is not intended as a standalone article, but rather as an informative outline of events and activities to help the reader understand the differences of instruction between the two sections of sample populations. Chapter 3 uses qualitative interviews to explore the cosmic dimensions associated with learning of astronomy and finds diverse perceptions of astronomical scales may influence preservice teachers’ mental organization of astronomical information. Chapter 4 further analyzes cosmic dimensions using quantitative analyses and specifically examines preservice teachers’ perceptions of scale and spatiality within the context of astronomy education. Findings from Chapter 4 show that perceptions of scale and spatiality are an interconnected set of learning skills which may greatly enhance the learning of astronomy. Chapter 5 describes how concepts of scale and spatiality may be operationalized within a secondary school science classroom in order to better understand the scaled distances of stars though an inquiry-based three-dimensional modeling activity. Chapter 6 briefly concludes the dissertation work. Due to the nature of this dissertation design, the conclusions chapter is quite succinct as previous chapters are designed with conclusions sections embedded within the body of the text as outlined by specific journal submission guidelines.

These dissertation ideas are presented in a formal setting so that the various research undertakings can be studied and analyzed. Qualitative and quantitative analyses of research data are present to support the claims made in this study. The results of this research combine with features of previous research in order to advance our understanding of how preservice elementary teachers think about and learn astronomy.
Preservice Elementary Teachers Learning of Astronomy

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DISSERTATION

Submitted in partial fulfillment of the requirements for the
degree of Doctor of Philosophy in Science Education
in the Graduate School of Syracuse University

May 2009

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3. PRESERVICE ELEMENTARY TEACHERS CONCEPTUALIZATION OF COSMIC DIMENSIONS

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-and-

I dedicate this dissertation to my loving family, Alan, Laurie, Mark, and Wayne whose loving support and motivation made the completion of this dissertation possible. Thank you.
CHAPTER 1

Introduction

*The Universe has its endless gamut of great and small, of near and far, of many and few. Nevertheless, in physical science the scale of absolute magnitude becomes a very real and important thing; and a new and deeper interest arises out of the changing ratio of dimensions when we come to consider the inevitable changes of physical relations with which it is bound up.*  

--- *Sir D’arcy Wentworth, On Magnitude (1917)*

1-1. *What is this study about?*

Many people throughout the ages have attempted to understand the Universe and world around us. Scientists conducted observations and experiments in order to investigate our surroundings while philosophers attempted to postulate theories of the Universe’s existence. People from all societies and times have, at some point, asked mind-boggling questions such as “why we are here on Earth?” and “what lies beyond?” These questions are not easy to think about yet people still seem to want to know, or in other words, want to learn. However, learning about the cosmos can be a very challenging endeavor for many people, including those who will ultimately be responsible for teaching cosmic ideas to children. Preservice elementary teachers are faced with the challenge of understanding accurate information about the cosmos. Yet, the pursuit of astronomic knowledge may be coupled with abstract descriptions of extreme scales associated with even the most basic cosmic concepts.

An example of the extreme scale and metrics of Space is the speed of light, which is often used as a descriptor of celestial dimensions. In 1926 the American physicist Albert A. Michelson won a Nobel Prize for his efforts working with light. He was able to accurately calculate the speed of light using a twenty-two mile experimental set up. His calculation streamed the universal speed limit at 299,796 km/s or 186,282.397 mi/s. (The
use of miles is used for familiarity of units.) At this speed, a beam of light would encircle the Earth approximately eight times in one second! If we examine this value a little more, a beam of light may travel 186,282.397 miles in one Earth-second which would equate to a voyage of approximately 5.7 trillion miles throughout one Earth-year! Breaching the edge of the Solar System at light speed, light would travel for 4.22 years (NASA, 2008) in order to reach the nearest star Proxima Centauri; which is representative of the average between-star distances (or star density) within the Milky Way galaxy (NOAO, 2009).

Certain strategies have been developed to help transform extreme astronomical dimensions into more familiar human-sized (Greene, 1999) metrics to facilitate mental cognition of colossal numbers. One method used by astronomers substituted large numbers with composite new units such as the astronomical unit. For example, the average distance between the Earth and the Sun (93,000,000 miles) was simplified into one astronomical unit or 1 AU. However, using these new units of distance, Proxima Centauri would still reside about 271,000 AU’s (NASA, 2008) or 271,000 times the average distance from the Earth to the Sun! Furthermore, close up observations of Proxima Centauri by Voyager 1 spacecraft (traveling near 38,700 mph) would take 73,000 Earth-years for the encounter (NASA, 2008)!

The sheer magnitudes of Space dimensions may be confounding to the casual learner. These examples illustrated that inherent to astronomical study was the extreme dimensions associated with cosmic magnitudes. The cosmic dimensions may serve as barriers to the conceptualization of celestial phenomena.

The lack of direct outer space experiences may be shared by the general population among society (except those lucky enough to travel into Space). Among the
general population, preservice elementary teachers prepare to teach by learning scientific concepts through preservice teacher preparation programs. The present research study attempted to understand how preservice elementary teachers thought about unfamiliar dimensions of Space and explored cognitive perceptions of astronomic scale and cosmic spatiality.

1-2. Learners’ thoughts on Space

The mysteries of Space have intrigued ancient mankind to conduct observations and construed inferences about celestial phenomena. However, ancient observational conclusions of the cosmos may not have always been interpreted correctly such as Ptolemy’s (85-165 AD) geocentric model of the Universe. Today, the tradition of Space exploration continues and modern technology facilitates the exploration of the cosmos more than ever. Yet even with the advancement of technology, research suggests that children through adults possess many misconceptions about fundamental astronomical concepts; including those of even the most familiar celestial objects.

Elementary school children possess fundamental misconceptions (Cohen & Kagan, 1979) associated with even the most familiar Moon. Children described patterns of Moon phases were due to the Earth’s shadow on the Moon (Barnett & Moran, 2002) or clouds interfering with observations (Trundle, Atwood, Christopher, 2007; Baxter, 1989). These lunar misconceptions are not limited to the young minds of elementary students. High school students indicated that Moon’s orbit about the Earth was the reason for lunar phases; however, also indicated incorrectly that the Moon must be in full Moon phase when a solar eclipse occurred (Trumper, 2001). The incorrect idea of Moon phases correlated to eclipse phenomena demonstrated a fundamental conceptual
mistrstanding of the Earth/Moon relationship. The misunderstanding of basic lunar
topics was also found among undergraduate and preservice elementary education students.
Preservice elementary teaching undergraduates expressed lunar phases were caused by
the Earth’s shadow cast onto the Moon’s surface (Trundle, Atwood, and Christopher,
2006) which reiterated explanations suggested by elementary school children
(Kavanagh, Agan, & Sneider, 2005).

The addition of the Sun into the Earth/Moon/Sun relationship added another
element subject to inaccurate conceptions. Preservice teachers expressed Earth/Moon/Sun
relationships by drawing visual-models found to contain inaccurate representations when
representing principles of orientations, scale dimensions, and eclipses (Gil Quilez &
Martinez Pena, 2005). The Earth/Sun scaled distances were described as the most
probable cause for seasonal change on Earth rather than the tilt of the Earth’s axis as a
function of orbit (Atwood & Atwood, 1996). The orbital position of the Earth/Sun system
is directly associated with the position of the Sun in the daily Earth-sky and was largely
misunderstood by preservice teachers (Kalkan & Kiroglu, 2007). Positional variations of
solar orientations are directly associated with the causation of Earth’s seasons. These pre-
existing fundamental misconceptions of basic astronomy phenomena provided the
motivation for the present research study. The widespread misunderstandings of
astronomy rampant in society, including preservice teachers, prompted this study to
investigate how specifically preservice teachers think and learn about the cosmos.

The persistence of such a basic misunderstanding of celestial events among
preservice elementary teachers exemplified the need to identify and correct such basic
astronomic phenomena. The potential deficiency in accurate astronomic comprehension
may endorse future elementary teachers to shy away from teaching astronomy in their classrooms; despite the prevalence of astronomy education standards (AAAS, 2008; NRC, 1996). Helping to prepare future elementary teachers to teach accurate astronomy may interrupt the perpetual passing of teacher-to-student misconceptions.

1-3. Why teach astronomy?

Society today has become inundated with news, pop culture and current events related to astronomy. Numerous television programs such as the Star Trek series, The Universe, and various anime cartoons are all based on Space related plots. Many more movies have been produced which portrayed Space related story lines. Classic movies such as: Lost in Space, 2001: A Space Odyssey, Star Wars, Alien, Star Trek, The Right Stuff, and Apollo 13 all are associated with Space exploration. But even more modern films such as: Independence Day, Red Planet, Contact, Mission to Mars, Armageddon, Men in Black, October Sky and the Astronaut Farmer all depicted plots heavily connected with astronomy. Hollywood movie productions and television networks can often present sensational representations of the cosmos which can reinforce inaccurate astronomical concepts (such as acoustic sounds in the vacuum of Space). However, the success of these productions highlighted how pop culture embraced stories coupled with Space.

Current Space-related events can be found printed among national newspapers and online periodicals. Current events such as Space shuttle missions (or unfortunate failures), Mars robotic explorations, Hubble space telescope imaging, the International Space Station, unmanned missions to outer planets, Moon-base programs, the X-prize, and of course, the on-going quest for extraterrestrial contact (SETI) are also well
documented in today’s society. Space exploration has been a forefront of society ever since taxpayers began funding astronomical missions as a result of the Space Race and continue to play a role in political theaters. An example of public interest in Space exploration can be seen in Figure 1-1.

Figure 1-1: Spectators watch as the Shuttle Endeavor lift off to the International Space Station.

Credit: Philip Andrews for The New York Times

The abundance of popular science oriented magazines such as Popular Science, Nature, National Geographic, Sky and Telescope, Space, Discover, Scientific American as well as Space and technology sections in major newspapers supported the general public’s interest in Space exploration.

With the technological advancement of electronic information, astronomy has become a mainstay in society-at-large. However, astronomy continues to be a science discipline less emphasized in public schools (Adams & Slater, 2000) even with well-defined elementary astronomy education benchmarks (AAAS, 2008)(Appendix A). Although astronomy education has become more inclusive with the advent of technology, the subject is often less emphasized in traditional school curricula than many others (i.e.
life sciences) (McKinnon and Geissinger, 2002). Percy (1998) highlights three main reasons, supported by national science education reform tenets, as to why elementary school teachers should incorporate astronomy education into the K-8 curriculum. Each reason is outlined in the following paragraphs.

1-3.1. Dictum One: Recruit and prepare future scientists.

The claim made here was that the promotion of astronomy education in schools may promote the interest of all sciences, not just astronomy. Since many different disciplines are associated with astronomy, astronomy education may provide a point of departure for students to become versed in the scientific endeavor as a whole. Astronomy education may be associated with physics, chemistry, biology, mathematics, technology, engineering, computer sciences, Earth/environmental sciences, and meteorology. However, the incorporation of astronomy education, while beneficial, must be done in a manner which provided meaningful learning and does not reinforce common misconceptions of astronomical concepts (Handelsman et al., 2004). Introducing children to astronomy in early grades can facilitate children’s development of accurate astronomical concepts and may provide a foundation for which to build future astronomy knowledge. This process of learning astronomy may be analogous to learning a language; where the pursuit of initial astronomy information must begin with the development of fundamental foundations of accurate astronomical concepts introduced in early grades.

1-3.2 Dictum Two: Natural curiosity about astronomical concepts.

This paper began by outlining the natural sense of natural curiosity about astronomical concepts in general. Percy (1998) suggested harnessing our natural sense of the cosmos while attempting to seek the ‘truth’ of our existence poses higher order
thinking demonstrative of a quality science education program. This aspect of astronomy education may provide a natural vehicle for which to become generally interested in the scientific endeavor, which in turn, may lead to other scientific discipline interest. For example, studying how humans engage in Space exploration may spark interest in the historical development of rocketry. This may lead students to become interested in the engineering of rocketry, computer programming, and technological innovation which may otherwise mask additional scientific topics. The study of rocketry may also ignite the curiosity of aerospace engineering by simply engaging personal interest. The ability to connect astronomical concepts with one’s natural curiosity may be a starting point in which to promote learning of science through informal settings such as science/space museums and planetariums. For example, consider the ability to spark interest in rocketry though astronomy education and combine this with a visit to the Smithsonian Air and Space Museum in Washington D.C. Ramey-Gassert (1997) suggested the connection of formal science concepts with those accessible at public informal science education institutions may provide a more meaningful learning experience than traditional school science environments. Astronomy can provide this connection as a means of generating personal interest in scientific fields and not necessarily those directly associated with astrophysics.

1-3.3 Dictum Three: Promote public interest in science and technology.

The inclusion of astronomy education may raise awareness of social aspects of science education within society. Rising Above the Gathering Storm (NAP, 2007) suggested careful attention must be placed on the ongoing advancement of scientific and technological industries of our country in order to maintain global economic
competitiveness. The advancement of science and technology may promote the next
generation of scientists and engineers in order to advance scientific innovation. Scientific
innovation includes the biopharmaceutical, aerospace, defense, transportation, energy,
agricultural, engineering, computer science, consumer, and educational industries of the
U.S. and global economies.

In addition, the promotion of astronomy education may increase awareness and
support of science and technology programs, funding agencies, and scholarships available
to society. With an increase of scientific awareness, citizens may become more informed
about scientific issues such as environmental conservation or energy. It is essential for the
well being of our society that all citizens develop a ‘scientific literacy’ defined as an
appreciation of science, the benefits of technology, and the potential risks associated with
advances in both (Sahoo, 2004). Astronomy education can provide the initial framework
which may facilitate public awareness of the sciences as applied to the world.

These three dicta associated with astronomy education highlighted how
astronomical concepts may play a larger role in science education reform. The overt
suggestions for the inclusion of astronomy among society and U.S. schools come with a
strategy for implementing Space science into classrooms as well as some problems with
astronomy education at-large.

1-4. Problems with astronomy education

Despite the current call for the inclusion of astronomy education into
elementary/middle school curriculum there still exist barriers which may inhibit
astronomy from being taught in schools. Percy (1998) highlighted eight possible
problems as to why astronomy education seemed to be neglected in traditional science education curriculum and can be seen in Table 1-1.

Table 1-1: Problems with astronomy education.

| (a) Students have common misconceptions about astronomical concepts (i.e. the causation of the seasons), which are not overcome by current teaching methods commonly used. |
| (b) Teachers have misconceptions about teaching astronomy (and perhaps astronomical concepts as well), which discourages them teaching astronomy well or not at all. |
| (c) Teachers (especially in elementary schools) have very little knowledge of astronomy, while astronomy has progressed by leaps and bounds. |
| (d) The most effective teaching tools are simple, inexpensive, hands-on activities and these are not widely used or widely available. |
| (e) Teachers are not aware of materials which are available in order to teach astronomy. There exists no national or international journal geared towards effective astronomy education. |
| (f) The best or most-fortunate students may receive astronomy education but underprivileged, minorities, students with disabilities, women, inner-city or rural students—and students in developing nations may be left out. |
| (g) The best students may be attracted to astronomy and astronomy education; and may be provided with career opportunities upon graduation. |


Although all problems are barriers to the inclusion of astronomy in the classroom, problem a, b and c are focused on how misconceptions may prove to be a hindrance for both students and teachers. Problem a also suggested that current teaching methods may not effectively overcome student misconceptions about Space. Some of the concerns listed above offer insight into why astronomy education may be less emphasized in daily classroom instruction (Harlen & Holroyd, 1997).

1-5. Dissertation design and research introduction

This research study was grounded in the field of elementary science education and was specifically focused on preservice science teacher preparation as seen in Figure 1-2.
The preservice elementary preparation program component of elementary science education fundamentally seeks to raise the quality of future elementary science teachers. The elementary science education program was designed and supported by the national call for science education reform (NAP, 2007) and is concerned with helping future teachers learn accurate science content and processes which help future elementary students learn science. The present study was concerned with only two aspects of preservice elementary teacher preparation which included: (1) raise preservice teacher understanding of fundamental astronomical concepts and (2) help prepare future elementary teachers to teach astronomy concentrating on specific astronomy topics. This study does not address issues of teacher-efficacy or implementation of astronomy education during in-service years.
Fullan (1993) asserted that teachers are the most likely change agent for educational reform which logically placed the emphasis of this study on the preparation of future elementary classroom teachers. This study focused on how preservice elementary teachers learned and conceptualized astronomical concepts associated with the extreme dimensions of Space. Qualitative interview data were first analyzed in order to understand how preservice teachers thought about cosmic dimensions. Then, quantitative analyses of preservice teachers’ perceptions of scale and spatiality were conducted. Data analyses were conducted within the context of learning astronomy.

1-5.1 The participants.

The participants in this study were preservice elementary teachers (n = 77) enrolled in either the treatment (n = 39) or the comparison section (n = 38) of a science course within an inclusive education program at a large northeastern university. Due to the relatively small sample size, a census was utilized in order to obtain data from all participants. The sample cannot be considered random due to potential bias in selecting course section. The program was for those who aspire to become grade 1-6 teachers and follows a strict teacher preparation program accredited by National Council of the Accreditation of Teacher Education (NCATE). In particular, the participants were enrolled in a required science content course designed to address content in the National Science Education Standards (NRC, 2003) and Benchmarks for Scientific Literacy (AAAS, 2008). Most participants were traditional freshman (91.0 percent). Although this course was designed for elementary preparation, some participants were not education majors. Participants’ majors included education (88.5 percent), business (1.3 percent),
humanities (6.5 percent), sciences/engineering (2.6 percent), and other/no answer (1.3 percent).

The sample self-identified a myriad of diverse cultural backgrounds and home communities. The largest majority of study participants were suburban (57.1 percent) white/non-Hispanic (77.9 percent) females (96.2 percent). Various other cultural backgrounds were represented as well as home communities as defined by the United States Census Bureau. Figures 1-3 and 1-4 are pie charts which represent the respective demographic background information. All participants’ ages ranged from 0-20 years old.

Figures 1-3 and 1-4: Demographic information of sample population.

The relatively homogenous sample population is typical of preservice elementary teachers. However, there were smaller percentages of culturally diverse participant populations which can help shape the future efforts of astronomy education. Astronomy has demonstrated to be a science without known boundaries and across human civilizations at-large. The subject matter can cross cultures and subject matters to help bring a well-rounded interdisciplinary study to the forefront of science education.
Celestial objects within the Universe are gender neutral (although some cultures refer to some as gender specific) and no one owns the cosmos. Therefore, Space is truly a theater without borders. The study of Space is a pursuit attainable by anyone who has a sense of wonder. This message can form a contextual basis for the inclusion of astronomy into an elementary classroom. Therefore, the inclusion of astronomy into the elementary classroom is just as important as the inclusion of astronomy into teacher education programs. The preservice and in-service components of teacher education can greatly benefit by learning to use astronomy as a vehicle for meaningful lessons which span the disciplines of sciences, social justice, mathematics, history, technology, the arts, and writing and literature. Chapter 5 describes how the study of astronomy can bolster nature of science tenets in greater detail.

1-5.2 The research questions

The goal for this study was to determine factors that may relate to preservice teachers understandings about astronomy. In order to accomplish this, the research was designed to specifically focus on certain aspects of astronomy education among preservice elementary teachers.

1. How do preservice elementary teachers conceptualize cosmic dimensions?

The abundance of astronomy misconceptions found among preservice elementary teachers (Ashcroft & Courson, 2003; Trundle, Atwood, & Christopher, 2002; Barba & Rubba, 1992; Abell, Maritni, & George, 2001; Atwood & Atwood, 1996) prompted the present research to explore how preservice teachers think about Space, given the vast expanses and spatial relationships in which the cosmos exist. Previous research suggested scale conceptions were related to students’ understandings at the micro scale (Tretter, Jones, Andre, Negishi, Minogue, 2006) and this study was designed to determine if scale
also had a relationship to understanding phenomena at the macro or astronomic scale. Previous misconception research neglects the scale component and that gap is addressed by this work. A set of qualitative interviews were conducted in order to understand various preservice teachers’ cognitive strategies and uses of language in which to conceptualize celestial relationships.

2. Do perceptions of scale and spatiality play a role when learning astronomy among preservice teachers?

The cognitive skill sets of scale perception and spatial aptitude have been shown to be effective tools when learning science as many fundamental concepts of science are firmly rooted in principles based on extreme scales and spatial orientations (Tretter et al., 2006; Black, 2005; Rudmann, 2002). In addition, the singular vantage point from an Earth-based perspective of the Universe challenges learners to create mental models of astronomical phenomena. Astronomical concepts are directly associated with unfamiliar scales and celestial orientations as the study of the cosmos expands across enormous vastness of Space. The cognitive proficiency of scale perception and spatial aptitude may prove to be paramount when studying astronomy. To date, no research has explored how these cognitive skills sets may work together in order to better comprehend astronomy within the context of preservice elementary teacher preparation. A flow chart of the logical procession for this research question identified the three sub-questions associated with this research question and can be seen in Figure 1-5.
Figure 1-5: Sub-questions and logical processing of research question
1-5.3 The assessment measures

In order to help answer these questions a treatment (experimental) and control (comparison) quasi-experimental research design was developed. The experimental group received an astronomy curriculum explicitly rich in astronomic scale and cosmic spatiality. The comparison group received an astronomy curriculum similar to traditional design as outlined by Zeilik et al. (1997).

Standardized measures were administered before and after the astronomy units which assessed astronomical comprehensions, scale perception and spatial-aptitude. Further detailed descriptions of statistical methodologies are presented in greater detail in the following chapters of this dissertation.

Four measures were used to collect data for analyses. Specific measure which assessed scale perception, spatiality, and astronomic comprehensions were selected as primary data collection measures. The Scale of Objects questionnaire (SOQ) (see Tretter et al, 2006) [Appendix B] was selected to assess participants’ understanding of scale. The choice to use the SOQ as a measure of scale is due to the limited number of valid scale assessments. The structure of the SOQ was arranged in such a way which was user-friendly, easily administered, and quantitative by design. However, the SOQ has not been used extensively as the instrument is relatively new and therefore was used in conjunction with a modified card sort activity to help strengthen the scale data used in this study. A modified card sort activity followed by a qualitative interview (see Tretter et al, 2006; Bogdan & Biklen, 2006) [Appendix C] was selected to help triangulate scale perception. The card sort activity was used to allow the participants the flexibility to use authentic scaling strategies to help organize scales of dimensions. This activity was
purpose selected to compliment the SOQ which provided an existing set of scale ranges in which to apply to object dimensions. The card sort was modified by adding 18 extra cards which were associated with astronomy. Follow up interviews helped the researcher better understand the individual participants’ strategies for sorting cards into scaled categories. Although the card sort data was quantified (followed by qualitative coded interviews), the measure has not been extensively validated. Therefore, the combination of various scale measures bolstered the validity of scale data collection. Future implementation may lead to a more robust validation of these scale measures. The Purdue Visualizations of Rotations Test (ROT) (see Bodner & Guay, 1997) [Appendix D] was selected to assess individual spatial aptitude. The choice to use the ROT over other spatial aptitude tests was due to the nature of the test design. First, the test was very well validated and known in the field of spatiality. Second, the test was also used a three-dimensional visual representations as mechanisms to simulate three-dimensional mental rotations. The three-dimensional aspect of each question more mimicked the three-dimensional physical world, especially when thinking about celestial objects above. Finally, the user-friendly ROT was simple to administer in a classroom. The test was timed in order to reduce analytical reasoning, which states, given long enough, the solution can be found. The ROT was meant to see how well one can mentally think about the movement and spatial orientations of three-dimensional objects. Therefore, for purposes of this research, the ROT was an ideal choice. The Astronomy Diagnostic Test (ADT 2.0) (see Slater, Hufnagel, & Adams, 1999) [Appendix E] was used to check for overall astronomical comprehension and was selected due to extremely validated and known conceptual diagnostic test in astronomy education. The ADT 2.0 was revised to
ensure one astronomical concept per question while 14 of the 20 questions had to do with cosmic scale and spatiality. However, the ADT 2.0 was not developed to directly measure scale and spatiality of astronomic concepts, yet was embedded within respective questions. The user friendly ADT 2.0 was readily available and easily administered within each section. In addition to astronomical concept assessment, there were a battery of 13 demographics and academic backgrounds added at the end of the survey. This information was necessary for this research study and therefore, the ADT 2.0 was selected as the astronomy assessment of choice.

This dissertation was designed to be journal-ready which means specific chapters address specific question(s) raised by the researcher. Chapter 2 provides in-depth description of the actual day-to-day astronomy activities conducted within each respective section of research group and is not intended to be a standalone article manuscript. Chapter 2 is included to give the reader the description of the differences between the astronomy curriculum designs for each section as these differences become important comparisons of analyses for subsequent chapters. Chapter 3 provides a qualitative exploration of preservice teachers’ conceptualization of Space. The qualitative data were supported by quantitative analyses which helped identify major themes of discovery. Chapter 3 was written and formatted as a standalone manuscript according to the specific submission guidelines outlined by The Astronomy Education Review. Chapter 4 provides a quantitative exploration of preservice elementary teachers’ perception of scale and spatiality when applied to the context of learning astronomy. Chapter 4 was written and formatted as a standalone manuscript according to the specific submission guidelines outlined by The Journal of Elementary Science Education. Chapter
5 was written as an article designed to emphasize how concepts of scale and spatiality can be used to facilitate students’ learning about stars. Chapter 5 was written and formatted as a standalone manuscript according to the specific submission guidelines outlined by The Science Teacher. The manuscript contains sidebars, which are supplemental informative text used to broaden the article context and text boxes, which are used to illustrate common children’s responses to key parts of the proposed lesson. In addition, numerous figures are supplied at the end of the manuscript per request of the editor. The formatting features are stylistic and encouraged by the editor of the Journal. The Science Teacher is a publication of the National Science Teachers Association with a secondary education level focus. Specifically, this journal provides reviewed articles which are designed to disseminate lessons of teaching and learning science at the secondary level to in-service teachers.

Due to the nature of this dissertation format, journal-ready chapters are designed to be manuscripts for specific journals and therefore, this dissertation may not resemble a traditional dissertation format. However, each appropriate chapter outlines specific methodology and information about the participants with regards to the research question, data collection devices, analyses, findings and discussions gleaned from the research.

1-6. Conceptual change in science education as guiding frameworks

This study is fundamentally grounded in conceptual change as a guiding framework in which to explore astronomy education. The field of science education faces the challenge of helping people learn about the natural world while competing with individuals’ unique experiences. These unique experiences help shape their daily habits, thoughts, actions, and beliefs which may sometimes conflict with a scientifically
accepted concepts. The challenges lead to the inception of the constructivism educational model and helped shape the field of conceptual change within science education.

From the outset, conceptual change initiatives were focused on learning disciplinary content for conceptual change (Posner, Strike, Hewson, & Gertzog, 1982) yet has evolved to teaching for conceptual change as well (Hewson, 1992). The logical progression of conceptual change work in the field of science education has guided this research to refine the conceptual change reform efforts to astronomy education among preservice elementary teachers.

This brief overview of conceptual change efforts in science education is meant to help the reader identify the lens in which this research study was grounded. Each successive chapter of this dissertation outlines the conceptual change constructs in much greater detail as they apply to specific research focal points.

1-7. Discussion and conclusions

As mentioned earlier, there are many gaps in the world of astronomy education and many problems as well. The limited time of science content and experiences associated with elementary teacher preparation (Jarrett, 1999; Manning, 1982) programs beckons the need for understanding effective strategies associated with learning astronomy. The limited formalized science preparation signals the need to incorporate the most effective strategies in which to prepare future teachers to teach accurate astronomy to children. Therefore, we need to understand how to best incorporate astronomy education into the limited extent of formalized science content as part of the elementary teacher preparation program.
Elementary teachers can be enthusiastic about our place in Space, and may influence future generations of citizens to embrace astronomy into their lives. And whether their students end up being amateur tinkerers or professional scientists, at least the promotion of astronomy may help teachers guide children to make informed decisions about their lives, community, country, and Mother Earth.
CHAPTER 2

The Intervention

2-1. The Intervention

This intervention outline was written in order to explain the differences between the experimental and comparison groups’ astronomy curriculum which was administered during the present study. The intervention was carefully designed in order to explore whether curriculum explicitly rich in concepts of scale and spatiality facilitated conceptual understanding of astronomical concepts and was based on national Benchmarks 4A-D: The Physical Setting (AAAS, 2008).

2-2. The physical classroom environment

The intervention lasted seven eighty-minute course periods and instruction took place in two classrooms, building hallways, and one small work area. The main classroom was a small, flat lecture-style carpeted room which seated about fifty students along joined tables. There was a demonstration table located in front of a large blackboard with a large retractable projection screen in front of the blackboard which displayed multimedia images. The lecture room was appointed as academic/instructional use only; and therefore had no laboratory capabilities. The other classroom was appointed as a safe laboratory space with all necessary safety systems in place for full science laboratory instruction, sat about thirty students, and had smart technology capabilities. The small work area was an appointed department office which contained no windows. This room was beneficial for the study of astronomical concepts associated with low-light levels and fundamental properties of light. The building hallways provided a calm and safe place in which to conduct lessons and activities associated with long distances.
Overall, numerous physical spaces were utilized in order to facilitate the implementation of the astronomy curricula for research purposes.

2-3. The daily plans

2-3.1 Day 1- Relative scales of the Earth/Sun/Moon.

Day 1 introduced the relationship between the three most common objects in the Earth’s sky. Specifically, the relative scales of properties of the Earth/Moon/Sun were explored. This unit was based from the national Benchmarks:

- The Sun, Moon, and stars all appear to move slowly across the sky.
- The Sun is many thousands of times closer to the Earth than any other star.

2-3.1.1 Comparison group

The comparison group began instruction using a PowerPoint presentation which was designed to compare the relative properties of the Earth/Moon/Sun system. The presentation began with a pre-assessment which asked paired students to construct a three circle template which they filled with pre-existing ideas about the Earth/Moon/Sun. Guided instruction then led students to think about various characteristics of the Earth/Moon/Sun such as: sizes, distances, and relative positions. Next, a PowerPoint presentation was shown which portrayed metrics and ratios describing celestial objects, a plethora of astronomical images, and two movie clips; one computer simulation which showed Earth/Moon/Sun relationships from Space (0:46) and as well as a time-lapsed movie of the Moon set and Sun rise above Lake Superior (0:40). A guided wrap up discussion provided an opportunity for reflection and closure. All notes and reflections were written in the participants’ science journal. The guided interactive presentation lasted approximately thirty-five minutes.
After the PowerPoint presentation, the game Who Wants to Be a Millionaire was played using concepts from class. Students had cards labeled A,B,C,D and raised their card with their answers. For example, one question was ‘How far is the average distance from the Earth to the Moon in terms of Earth diameters?’ This interactive game lasted approximately thirty-five minutes. The ten minutes left over were for administrative announcements and course questions.

2-3.1.2 The experimental group

The treatment group received an abbreviated PowerPoint presentation where some of the pictures and slides that were repetitive were removed. This provided more time for the planned scale and spatial rich lesson activities. For example, only one video clip was shown: the 3D computer simulation. This presentation was thirty minutes long.

The class was then split into two groups where half of the class moved into the laboratory and half the class stayed in the classroom. The group in the classroom worked on an Earth/Moon activity adapted from the Annenberg Media Math and Science Project Teachers’ Lab. The objective for this lesson was to use selected spherical objects such as tennis, bouncy, golf, table tennis, or basket balls as representative scaled models of the Earth and Moon. The participants selected a ball of their choice, and then paired with someone whom they thought had an appropriate sized ball representative of the correct scale sizes of the Earth and Moon. The participants then decided how far apart they ought to stand in order to represent an accurate scaled distance based on their particular sphere diameters. Participants were asked to make note of various groups representative models. Participants also estimated of how many ‘Earth objects (i.e. tennis ball)’ would be needed to string a straight line between the ‘Moon object’ and ‘Earth object’. In other words,
participants may have estimated 20 tennis balls apart. Once this activity was completed
the real answers were revealed. Participants found an appropriate partner given the
correct scales for their set of objects and re-positioned to the corrected scale distance.
(For example, if one pair of participants was a tennis ball as the Moon and a basketball as
the Earth, then they should have stood 8.4 meters apart.)

This activity provided an opportunity to learn about Moon and Earth scaled sizes
and distances with an emphasis astronomic scales and spatial orientations. Following this
activity, the Sun was included to extend the use of astronomical scale and spatial
orientations. However, doing this activity to include the Sun’s relative distance would
place the representative ‘Sun object’ 3360 meters away from the Earth on the tennis ball-
basketball scale, which was far too large for the scope of this activity. This activity took
twenty minutes.

After this activity was concluded, the groups switched rooms and activities. In the
laboratory, participants were engaged in an Earth/Moon Scale drawing activity developed
by the researcher. This activity used a pencil, half of an 11x17 piece of paper cut
lengthwise, a protractor, compass and ruler. Participants were asked to identify the scale
distances between the Earth and the Moon in terms of Earth diameters. (If the Earth’s
diameter was 1 centimeter, participants sketched a scale size Moon .25cm, and carefully
included the 5 degrees of lunar inclination.) On this scale, participants drew the 1
centimeter circle as Earth and .25 centimeter circle as the Moon approximately thirty
centimeters apart on a five degree deviation from the Earth’s ecliptic plane.

This activity represented a more accurate picture of the spatial orientations of the
Moon and Earth on a more accurate scale and can be seen in Figure 2-1.
Guided discussions extended to lunar Space exploration and briefly introduced the concept of an eclipse. However, eclipses were covered more in depth during the Moon activity on day 4. This activity took twenty minutes.

The class then rejoined for final wrap up and viewed a demonstration using NASA’s J Track website, which showed a real time view of all artificial satellites in orbit. Class ended with wrap up and questions. In each section, the experimental and comparison groups engaged in the same astronomic concepts associated with the Earth/Moon/Sun system. However, they were highly different curricula designs.

2-3.2 Day 2- The Sun and star light

Day 2 of the intervention focused on Sunlight intensity and illumination/reflection of star light. This section was based on the national Benchmarks (AAAS, 2008) for K-8 astronomy education standards:

- Stars look like the Sun, some being smaller and some larger, but so far away that they look like points of light.
• The Sun is a medium-sized star located near the edge of a disk-shaped galaxy of stars, part of which can be seen as a glowing band of light that spans the sky on a very clear night.

• Light from the Sun takes a few minutes to reach Earth, but light from the nearest star takes a few years to arrive.

2-3.2.1 The comparison group

The comparison group was shown an interactive PowerPoint presentation which focused on the generation of star light, how celestial objects were related to starlight, how star light propagated through Space, and the illumination and reflection of star light.

The comparison group began the lesson with a picture viewing activity. The participants were given eight photos representing real celestial objects from different vantage points and asked to write down detailed descriptions of observations. This gave the participants a chance to analyze real photos of celestial objects from various frames of references and perspectives. For example, one picture was a star field taken by NASA’s Hubble Space telescope from above our atmosphere and in contrast to a star field taken the surface of our Earth. In addition there were photos of the Moon and Sun from various perspectives. The idea was for participants to use observation skills to note subtle details about each image. Guided questioning of each photo facilitated note taking during the exercise and was directed toward understanding that: (1) objects in the sky are observable by the emission or reflection of star light; and (2) the intensity (magnitude) and perception of light was related to specific stellar properties (i.e. distance, brightness, temperature, and size).
The photo observation exercise was followed by another PowerPoint presentation which explored the fundamental process of nuclear fusion and light propagation through Space. The famous picture “Dark Rings of Saturn” was discussed as a group. The presentation took 40 minutes.

A class demonstration followed to explore the propagation of light through Space. Two volunteers were selected. One held a cut out of an object (Otto the Orange mascot) and placed it in front of the computer projector so to cast a shadow onto a screen with a square grid template (graph-paper). The object was moved back and forth in front of the projector which caused the cast shadow to change sizes (shadow area). The grid system on the projection screen allowed participants to estimate how many squares were in shadow versus the distance the object moved. This demonstration led into a thinking activity where the participants were asked to imagine and write down what the Sun would look like to them if standing on another planet in the Solar System.

Next, a pencil and paper activity began which formally introduced the Inverse Square Law. Participants computed relative solar intensities (RSI) for each planet in the Solar System (including Pluto) based on supplied NASA data sets and were converted to percentages. For example, Mars was listed as approximately 1.5 AU from the Sun. A quick calculation of inverse square ratio yielded a relative solar intensity of 0.431 or 43.1%. This means that the relative Sun’s brightness in the Martian sky is roughly 43.1% of what we see in Earth’s sky. The demonstration and solar intensity activity took 30 minutes and was adapted from educational tools designed by the Christa McAuliffe Planetarium in Concord, NH. The remainder of the class was used for administrative tasks and questions.
2-3.2.2 The experimental group

The experimental group received the same PowerPoint presentation but did not participate in the photo observing activity. The presentation lasted 30 minutes. The experimental group engaged in three different activities for the next part of class. At three stations, participants worked on three different activities.

One station took place a small dark office and was titled Sunlight Intensity Activity which was developed by the researcher. The activity involved a group of five participants to enter a nearly blackened room. The blackened room was achieved by setting up equipment in a windowless room in the building. A 3 meter Pasco track was set up with average planetary orbit distances set to scale using a representative 5 millimeter diameter Sun as a reference point. This was achieved by placing a light bulb inside a box with a 5 millimeter hole to allow light to shine through. The approximated orbital paths fit to scale but only out to Jupiter (a few centimeters short). The outer planetary scales were beyond the scope of the room and equipment capability. The relative Sunlight intensity does not exactly match the scaled intensity of the Sun’s actual flux, but the relationship between relative light intensity and distance did plot to an inverse square function. Data were collected by using a Vernier light detector probe connected to a Vernier LabQuest console and software package as seen in Figure 2-2 and 2-3.
Data were recorded for both distance away from light source (cm) and measure of light intensity (lumens) from LabQuest software output. Once data were collected, participants returned to the classroom where they constructed a graph of their data and answered guided questions. Another group of five entered and repeated.

The second station was located in the laboratory classroom; a room that was fairly darkened. The activity designed by the researcher explored the concept of surface light reflection (albedo). The device used two cardboard tubes connected in a ‘V’ shape that was flat on the bottom. The upper right opening of the ‘V’ hosted a light source (common flashlight) and the upper left opening of the ‘V’ was the point of observer observation as seen in Figure 2-4.

Figures 2-2 and 2-3: Light intensity activity set up.

Photo Credit: Chuck Fidler
Under the flat part of the ‘V’ (or bottom junction) were various changeable colored paper surfaces (such as red, black, white, gold, and yellow paper, and a mirror). The activity allowed participants to observe how much light is absorbed or reflected by relatively ranking the brightness inside the tube. This was procedure was synonymous to analyzing different planetary surfaces, such as the contrasting surface of the Moon. (The Moon’s surface may look lighter and darker according to the reflection and absorption of the Sun’s light according to lunar surface material.)

The third station utilized the same computation of relative solar intensities (RSI) activity as the comparison group except the experimental group was asked to write a comparison between the calculations of RSI and the data collected during the Sunlight Intensity Activity. These activities lasted for 40 minutes.

Both groups received instruction on concepts related to Sunlight, star light generation, and how star light interacted with celestial objects such as the Moon and
Earth. This lesson primarily discussed the interaction of Sunlight with the lunar surface. The next day focused on how Sunlight interacted with the Earth during the yearly solar orbit.

2-3.3 Day 3 - Earth orbit and seasons

Day 3 focused on the interaction of Sunlight and the Earth as the Earth orbited the Sun and was based on the following national Benchmarks (AAAS, 2008):

- The Earth is one of several planets that orbit the Sun, and the Moon orbits around the Earth.
- Different stars can be seen in different seasons.

2-3.3.1 The comparison group

The comparison group received a PowerPoint presentation associated with the concepts of Earth orbit. A pre-assessment question was administered which asked the participants to answer, ‘I think the reason we have seasons on Earth is…’ The question also asked participants to sketch the Earth’s orbit about the Sun as this data was used to help shape future discussion. The pre-assessment took 3-5 minutes.

After the pre-assessment, the participants viewed an interactive PowerPoint presentation. The presentation explored how the orientation of the Earth’s tilt was the main cause of Earth’s seasons and addressed the common misconception that it is summer when we were closer to the Sun and winter when we were further away. A review of previous day’s instruction led to a demonstration which simulated Sunlight interacting with the Earth’s surface. A beach ball and a flashlight were used to help demonstrate how light ray intensity varies over greater distances and surface area, while the amount of light from the Sun is relatively constant. The slide included a video animation (1:05) as well.
The slide show focus shifted onto children’s representations of Solar System orbits and explored some examples of published orbital representations. The whole presentation and interactive demonstration took 40 minutes.

A video clip about the misconceptions of the causation of seasons from the famous A Private Universe (Schneps & Sadler, 1985) was shown followed by guided discussion. The participants then engaged in a written reflection re-visiting their pre-assessments from the first part of class. This data was collected for analyses and took 25 minutes.

2-3.2.2 The experimental group

The same pre-assessment and beach ball demonstrations were shown to the experimental group. The PowerPoint slide show was abbreviated but did include the video animation (1:05) of Sunlight intensity and seasons. The abbreviated slide show took 30 minutes.

The demonstration previously done was followed by a scale size demonstration of the Sun/Earth distance. The NASA developed activity supplied a scale cut out of the relative diameters of the Earth and Sun. The participants used these scale sizes to represent a correct average spatial distance between the Earth and Sun (At this scale, the distance was 65 feet, which was measured in the building hallways) as seen in Figure 2-5.
The experimental group returned to the classroom where they engaged in a researcher designed activity which used National Oceanographic and Atmospheric Administration (NOAA) data from the AIRS satellite to construct a graph of average mean temperatures as a function of time. The two data sets were for the cities Melbourne, Australia (37.82° S longitude) and Washington D.C., USA (38.85° N longitude) which reside at roughly the same latitude but are located in opposite global hemispheres. Guided discussion and follow up questioning helped to illustrate that temperature in the two hemispheres were opposite based on the tilt of Earth and the position of orbit. The questions and graphs were entered into their science journals. This activity took 20 minutes.

Finally, the remainder of time, participants watched A Private Universe clip on seasonal misconceptions. The participants wrote their reflections and handed them in after they watch the video. This activity took 20 minutes.

The concepts were the same between the two groups with the addition of a heavier emphasis on misconceptions of seasonal causations in the comparison group.
However, the experimental group received the same video and opportunity to reflect as the comparison group. The experimental group engaged two activities that demonstrated correct scales of sizes and distances for Earth/Sun system.

2-3.4 Day 4- The Moon

Day 4 was focused on the Moon. In particular, emphasis was placed on a more detailed exploration of the Earth/Moon relationship related to lunar phase and lunar and solar eclipses. The choice to include a section on this was based from the national Benchmarks (AAAS, 2008):

- The Moon looks a little different every day, but looks the same again about every four weeks.
- The Sun can be seen only in the daytime, but the Moon can be seen sometimes at night and sometimes during the day.

2-3.4.1 The comparison group

The comparison group listened to a PowerPoint presentation that began with some basic information about the Moon including a slide on the most accepted theory of lunar formation. (Evidence supporting this theory was presented in the form of elemental compositions (%) of surface rocks.) A list of major elements in the human body was presented for comparison and extension. The presentation included a slide on comparative geology (including erosion and atmospheres) and was presented with panoramic views of the lunar, Earth, and Martian surfaces. Students recognized the absence of a lunar atmosphere and a guided discussion facilitated how this was related to the Moon’s topology.

Next, the presentation took a closer look at the Moon’s orientation and orbit about the Earth. Slides were then shown to illustrate the orbital inclination of the Moon and the
orientation between the Earth/Moon/Sun systems. This led into a series of slides that showed various positions of lunar orbit and how this was associated with Moon phases. The concept of lunar orbital inclination was presented which led into discussion about eclipses. Both lunar and solar eclipses were then presented by showing numerous NASA images. Two video clips showed examples of 2006 solar eclipse in Turkey (2:05) and lunar eclipses (1:20) with computer graphics. The presentation and video clip took 40 minutes. The comparison group then paired up and attempted to draw an accurate diagram of lunar inclination and phases of the Moon (only the major four) in their science journals. This activity took 10 minutes.

After this was completed, a clip from A Private Universe was shown which gave the participants an idea about how children and adults thought about phases of the Moon. The video and discussion took 20 minutes.

2-3.4.2 The experimental group

The experimental group received an abbreviated PowerPoint presentation. The slides representing the Moons position around the Earth were taken out (however, leaving in slides for lunar inclination), therefore shortening the presentation to 25 minutes. The class was now split in half and occupied two different stations located in the classroom and laboratory. In the classroom, the participants were involved in an interactive demonstration which simulated a three-dimensional spatial representation of the Earth/Moon/Sun system. The Earth and Moon were scaled relative to one another; however, an overhead projector was used to represent the Sun. A basketball and a tennis ball represented Earth and Moon, respectively. Volunteers were asked to hold the objects and orient them to model the Earth/Moon/Sun scaled system (keeping in mind lunar inclination from the previous day). The lights were turned off and the overhead projector
(Sun) was turned on. As the volunteers move the Moon about the Sun, participants saw that the scale distances and spatial orientations were the reason for both the occurrence and absence of eclipses. Guided discussion continued referencing the scale drawings constructed in a previous class session. This activity lasted for 20 minutes when participants switched rooms.

The darkened laboratory was set up with tables moved out of the way for participants to be able to walk around. In this Annenberg Media Math and Science Project Teacher’s Lab activity, the participants used their body to represent the Earth with their nose as a reference point. A bright light source was illuminated in the center of a participant arranged semi circle. The participants were asked to point their nose toward the projector light as being representative of how the Sun would look in the sky at noon. Next, participants were asked to orient their nose as to where the Sun would be at midnight. Participants moved from right to left in a circular motion in order to simulate the Earth rotation. Participants were handed a small Styrofoam ball on a pencil and asked to hold at arm’s length, space apart, and observe how light fell on the Moon as the participants rotated around as seen in Figure 2-6.

**Figure 2-6: Lunar phase activity.**

Photo Credit: Chuck Fidler
Guided discussion helped participants understand the different frames of reference often used to describe the Moon’s phases. The spatial orientation of this activity provided an alternative method for representing the occurrence of lunar phases. This activity lasted for 20 minutes.

The experimental and comparison groups both received the same basic information about the Moon. The comparison group received a much more traditional, text-based curriculum design whereas the experimental group was engaged in activities heavily laden with concepts of scale and spatiality.

2-3.5 Day 5- The Solar System

Day 5 was dedicated to the exploration of celestial objects within our Solar System and was based on the following Benchmarks (AAAS, 2008):

- Planets change their position against the background of stars.

- Nine planets of very different size, composition, and surface features move around the Sun in nearly circular orbits. Some planets have a great variety of Moons and even flat rings of rock and ice particles orbiting around them. Some of these planets and Moons show evidence of geologic activity. The Earth is orbited by one Moon, many artificial satellites, and debris.

- Large numbers of chunks of rock orbit the Sun. Some of those that the Earth meets in its yearly orbit around the Sun glow and disintegrate from friction as they plunge through the atmosphere-and sometimes impact the ground. Other chunks of rocks mixed with ice have long, off-center orbits that carry them close to the Sun, where the Sun's radiation (of light and particles) boils off frozen material from their surfaces and pushes it into a long, illuminated tail.
2-3.5.1 The comparison group

The comparison group was engaged in a technology day which accessed NASA/JPL’s Solar System Exploration website. The limited numbers of PowerPoint slides provided an introduction to and instructions for an internet-based computer activity. The participants worked in groups of three and accessed the websites at an instructional computer lab reserved specifically for the course. The participants were asked to define and record the International Astronomical Union (IAU) definition of a planet. The definition was connected to a video clip about the status of Pluto as a dwarf planet. The participants began to explore planets, asteroids, and comets on their own. For each celestial object, participants reviewed and recorded: (1) general celestial descriptions, (2) Moons, (3) discoveries, (4) average distances from the Sun, (5) orbital periods, (6) two interesting facts such as how much they weighed or the possibility of human exploration. Data was organized using individual preferences. At the end, students watched a video clip (3:03) explaining why Pluto was no longer considered a major planet. This activity took 70 minutes.

2-3.5.2 The experimental group

The experimental group received an abbreviated version of the NASA/JPL Solar System Exploration activity. The experimental group used the website to collect data on all major and dwarf planets. Emphasis was placed on obtaining actual planetary diameters and average distances from the Sun. Participants, in groups of four, used paper, scissors and colored markers to make cut outs of each planet with specific regard to respective relative sizes. This activity lasted for 15 minutes.

Once information has been collected and cut outs have been made the class was split. One group utilized the expansive hallway where they constructed a scale model of
the Solar System using a roll of toilet tissue as a tape measure which was developed by the University of Montana Department of Astrophysics. Participants were asked to guess where each celestial object would reside if starting at a fixed position (toilet tissue square one). The participants started at the same point and used the scale 1 square of toilet tissue equaled 10,000,000 miles and taped each celestial cut out at proper scaled distances along the toilet tissue measuring tape. (The distances and numbers of squares were provided to save time.) The extension for this activity challenged the participants to predict the square of toilet paper the closest star would be located at this scale (Answer = 200 miles or 2.5 million sheets away). Participants were encouraged to bring the toilet paper scale back to the long hallways of their dormitories and set the toilet paper roll on display. This activity took 20 minutes.

After this activity, the groups changed locations and engaged in a computer based activity. The participants used Google Earth as a scale/spatial tool to help learn about relative Solar System distances. Google Earth was manipulated so participants could use any point on Earth as a starting reference point. In this case, the reference point was the location of the Sun. Faculty at University of Massachusetts Department of Science Education (2006) developed a bitmap overlay which was inserted into Google Earth as seen in Figure 2-7 and 2-8.
The two transparent overlays were embedded with both inner and outer planetary orbits to a correct scale. Participants were instructed to pick a reference starting point, for example, their house in their hometown, and inserted the overlay over their homes. The overlay showed where various orbits are in relation to their house (i.e. two towns over would be Mars, or is Neptune in another state). To keep the planetary scales manageable, inner and outer planets were seen by inserting two different overlays. Participants were asked to write down in their science journals what they did and described where each planetary orbit was found in relation to their reference point. This activity took 20 minutes.

The comparison and experiment groups were presented with very similar information regarding the Solar System. Specific technical information (i.e. interior compositions, escape velocities, names of all the Moons, density, sidereal rotation period) are not required by the standards at the elementary/middle school grade levels. Therefore,
more general information of the accurate sizes, positions, orbital paths of the planets was emphasized which was considered to be appropriate for the elementary/middle grade levels. The comparison group was exposed to a very traditional quasi-web quest that may be commonly found in the classrooms. However, the experimental group engaged activities that were heavily associated with concepts of scale and spatiality.

2-3.6 Day 6- Scales of the Universe

Day 6 was dedicated to the exploration of scales of the known Universe and was based on the national Benchmarks (AAAS, 2008):

- Telescopes magnify the appearance of some distant objects in the sky, including the Moon and planets.
- The Universe contains many billions of galaxies, and each galaxy contains billions of stars.
- To the naked eye, even the closest of these galaxies is no more than a dim fuzzy spot.
- A trip to the nearest star would take thousands of years on the fastest rocket.
- Some galaxies are so far away that even their light takes several billion years to reach the Earth. Therefore, people on Earth see them as they were that long ago.

2-3.6.1 The comparison group

The comparison group started with a pre-assessment which asked paired participants to answer: (1) how did the Universe began, (2) how big is the Universe, (3) how old was the Universe, and (4) do you think we are alone. Answers were written in their science journals. This activity took ten minutes. (Note: due to the nature of the
content in this section, times for activities were slightly extended due to the high number of questions that come up.)

Following the pre-assessment, the participants viewed a PowerPoint Presentation that introduced the Big Bang theory and Edwin Hubble’s discoveries. A closer look into how astronomers discovered information about the Universe by analyzing light led to the question, ‘How do we know all this?’ The presentation explored various different telescopes designed to collect data and how they were used by society to help answer some questions about the nature of the Universe. The presentation included an abundance of NASA images and included time for discussion. This activity lasted 40 minutes.

The comparison group was shown a 15 minute video clip of the IMAX DVD ‘A Cosmic Voyage’ and engaged in a discussion about scales of the Universe presented by the film. A product description of the movie can be found below.

*Cosmic Voyage mixes ground-breaking computer animation with cutting edge science to give us a sweeping view of the Universe. A "cosmic zoom" extends from the surface of the Earth to the largest observable structures of the Universe, and then back down to the sub-nuclear realm - a guided tour across some 42 orders of magnitude. Cosmic Voyage explores some of the greatest scientific theories, many of which have never before been visualized on film. – IMAX*

For timing purposes, the section of the film which dealt with magnitude greater than $10^0$ was shown.

2-3.6.2 The experimental group

The experimental group received the pre-assessment first just like the comparison group and shown an abbreviated version of the PowerPoint presentation. Some repetitive slides were taken out to shorten the presentation to 25 minutes. The class was split into two groups where one half moved into the laboratory. In the laboratory, participants
explored the expansion of the Universe in three-dimensions. The lesson plan, designed by the Discovery Channel School’s Curriculum Center, engaged the participants to use a balloon to simulate the Universe expansion. Participants began by drawing dots on the balloon and labeled one ‘Home’, representing the Milky Way Galaxy and included other dots, or galaxies, as seen in Figures 2-9 and 2-10.

Figures 2-9 and 2-10: Expanding Universe on a balloon activity.

The participants designed data tables in order to collect and organize their data. The data points were gathered as participants measured the distances from ‘Home’ to various dots after consecutive iterations of blowing up the balloon. Each round of air increased the diameter of the balloon by approximately two inches. In order to measure distance between the dots on a curved surface, participants were given measuring tape similar to ones used by tailors. Once data collection was completed, participants wrote in their science journals answers to the following questions; (1) how did the distance from the home dot to each galaxies (dots) change each time you inflated the balloon? (2) did the
galaxies near home or those farther away appear to move the greatest distance? This activity lasted 20 minutes.

When back in the classroom, the participants explored the time-scale of the Universe. This lesson was based on Carl Sagan’s “Cosmic Calendar” from his television show *Cosmos* and was adapted by the Discovery Channel Education and the American Museum of Natural History. This lesson plan was titled “The Universe in One Year” and was selected by the National Science Teacher Association and the American Association for the Advancement of Science as an outstanding lesson. In groups, the participants were given a monthly calendar and a list of ten significant times in the Universe’s history. (For example, the first formed galaxies, earliest dinosaurs, earliest homo-sapiens, the Big Bang, the formation of the Solar System, first life on Earth, first human hunter-gatherers, etc.) The challenge was to have groups of participants mark the calendar with each event. The origin of the Universe was designated as January 1 and December 31 was present day. When completed, the class discussed where the events should have been placed on the cosmic calendar. An electronic version was displayed using the document camera to make a class-consensus calendar. Results were then revealed. This activity took 20 minutes.

Many of the standards in this section were re-visited in more detail in the next section (Stars) but were included here as they were more aligned with Universe scales. The experimental and comparison group both received content associated with various scales of the Universe. However, the experimental group was given scalar and spatially oriented activities as part of the instruction. The comparison group received a much more traditional presentation followed by a movie that had to do with scale of the Universe.
2-3.7 Day 7- The stars

Day 7 was dedicated to the exploration of stars and was based on the following national Benchmarks (AAAS, 2008):

- There are more stars than one can easily count, but they are not scattered evenly, and they are not the same brightness or color.
- The number of stars than can be seen through telescopes is dramatically greater than can be seen by the unaided eye.
- The patterns of stars in the sky stay the same, although they appear to move across the sky nightly.

After exploring some relative scales of the Universe, the concept of stars may be more understandable as various aspects of stars were presented. Based on our singular vantage point on Earth, the vast distances, sizes, intensities, and distributions of the stars may be conceptually difficult to understand. In addition, the vast distances make the stars appear to be points of light on a two-dimensional plane in the sky, yet stars reside in the 3-D (4-D if you include time) realm of space-time. The concept of a light-year as a measure of distance was introduced however, although distances were supplied in light-years, the relative position was of more importance than actual numeric metrics. (For example, this section asked for the participants to recognize that 1400 light-years were twice as far as 700 light-years.) The concept of a light-year was found to be conceptually difficult as most humans do not experience this vast distance.

2-3.7.1 The comparison group

The comparison group engaged a pre-assessment where in pairs, they were asked to list what they believed children thought about the stars. An interactive PowerPoint
presentation showed a series of optical illusions which were associated with distance and blurred observation. The point of these slides was to represent that using optical sensors (such as our eyes) may cause some inaccuracies when observing objects as far away as the stars. The concept of parallax and frame of reference were included in this section as well. Participants then observed different sized pictures of the Moon and were engaged through guided discussion. The rationale up to this point was to allow the participants an opportunity to understand why we see the stars the way we do. Slides were presented which derived the light-year as unit to describe stellar distances, however, the manipulation of these metrics were used relative to each other. This presentation lasted 25 minutes.

The participants engaged a challenge activity where they were shown a high quality image of the constellation Orion the Hunter via computer projection. The choice for selecting Orion the Hunter as a constellation of study was due to its popularity and visibility in the northern hemisphere. The nine major stars (including the Orion Nebula) were labeled with letters A-I as seen in Figure 2-11.
The participants were asked to predict the ranking of star distances from closest to furthest from Earth. Participants discussed selection criteria with a partner and then wrote down their predictions. A guided discussion was conducted and class ideas were written down with regards to ranking criteria. Once this was completed, the correct ranking of the stars were revealed. (One of the brightest objects (Orion Nebula) was actually the furthest object (1,600 ly) and the three main stars that make up Orion’s famous belt look almost identical, yet were actually varying distances away.) The rationale for this activity was to use previous information from slides and apply them to a real view of stars. This activity took 15 minutes.

The participants watched a video clip (3:03) about the life and death of stars designed for elementary/middle aged students and served as a bridge for the next activity. The video was developed by the Spitzer Science Center and NASA as an educational outreach program series titled “Ask an Astronomer”. After the video clip, the participants formed into groups of three and received a slip of paper with known common children’s
(and adult) misconceptions about stars compiled by Operation Physics (AIP, 1998) (i.e. all stars are the same distance away from Earth, the galaxy is very crowded, and all stars in a constellation are near each other). Participants discussed their misconceptions, responded in their science journals, and presented their thoughts to the class. Whiteboards and dry erase markers were available to support the presentation of participants’ ideas. This activity took 20 minutes.

2-3.7.2 The experimental group

The experimental group started class with a slightly different pre-assessment question ‘How do you think about stars?’ The experimental group explored the stars with the same PowerPoint presentation. The experimental group copied the comparison group by making predictions of relative stellar distances of the stars in the constellation Orion the Hunter. This part of class took 15 minutes. The experimental group then engaged an activity developed by the researcher.

The activity challenged the participants to create a three dimensional scale model of the constellation Orion the Hunter. Participants were given materials and a data table of names of the stars, distance from Earth in light years, and a conversion column. For this scale, 1 centimeter equaled 200 light years. Participants glued down a color print out of the same constellation of Orion the Hunter onto a piece of appropriately sized black 1 inch foam board. The participants converted the light year distances to scaled lengths. (For example, the distance to the giant star Betelguese is 427 light years. On this scale, that was equated to 2.1 centimeters.) Participants then carefully measured this length on a wooden skewer (used in cooking), added an extra centimeter (to allow the skewer to stick into the foam board), and cut to length. The skewer was then inserted into the proper star one centimeter in depth. The stars distances were now represented by the length of the
skewer scaled. This process was repeated for all nine stars. The result was a three-
dimensional scaled model of the relative distances to most of the stars in the constellation
Orion the Hunter as seen in Figures 2-12 and 2-13.

Figures 2-12 and 2-13: Models of the constellation Orion the Hunter activity.

All stellar distances were double-checked and reviewed by Dr. Gianfranco Vidali an
astrophysicist at Syracuse University Department of Physics. However, even among
astrophysicist community there was some degree of uncertainty for some stars. The
distances associated with this activity were the most accepted in the field of astronomy
and were obtained from the Sloan Digital Sky Survey housed at the University of
Chicago and was supported by the National Science Foundation, NASA, and US
Department of Energy. This activity provided a method exploring the vast scales and
distances of the stars in a manner associated with concepts of scale and spatiality. Thirty
minutes was allocated for this activity. Guided discussion helped participants think
critically about the scaled 3D model activity.
Both the comparison and experimental groups received astronomy content associated with stars and were grounded in national Benchmarks (AAAS, 2008). However, the comparison received a much more traditional approach to learning stars. Although interactive, the curriculum was very traditional and not explicitly rich in scale concepts or spatial cognition. Every image except for one showed the stars on a two dimensional plane. One image taken by Hubble Space Telescope was a series of three images where the telescope zoomed in to certain areas of stars. The curriculum for the comparison group did not explicitly ask participants to think in a scalar or spatial manner, where as the experimental curriculum did.

2-4. Discussions and conclusions

This concluded the astronomy unit program. All elementary/middle level astronomy Benchmarks were included within this astronomy unit. Both the comparison and experimental groups explored similar astronomy content. The two groups greatly differed in the style of curriculum implemented within each section. The comparison group, although presented content associated with scale, were never instructed to directly think about astronomical concepts in terms of astronomic scale and cosmic spatiality. Some participants may have employed these cognitive skills sets on their own which may have facilitated the learning of abstract astronomical concepts. However, the experimental group was engaged in activities what were explicitly rich in concepts of astronomic scale and cosmic spatiality. All the activities called for participants think about the astronomical concepts from different reference points, including scales or ratios, etc. For example, during the Solar System lesson, the comparison group was meant to learn about the distances of the planets by using NASA’s Solar System
Exploration website where they explored the website and record the average distance from the Sun to the planets (i.e. Saturn is 885,904,700 miles). However, the experimental group was asked to retrieve the same information which used the same website, but then engaged two activities; (1) building the scale model of planetary distances which used a roll of toilet tissue, and (2) used a Google Earth application to allow participants to generate reference points when thinking about scaled planetary distances. Both of these activities explicitly guided students to employ scale skill sets when learning the vast scales of planetary orbits.

Another example was found during the scale of the Universe section. Conceptualizing the expansion of the Universe can be very difficult. The comparison group was given a PowerPoint presentation with computer generated images of how the expansion may be conceptualized. Two more analogies were given, the classic raisin bread analogy and separated scissors demonstration. Next, they watched a portion of a DVD which gave some representation of the scale and expansion of the Universe. However, the treatment group received a very similar PowerPoint presentation and then conducted the Big Bang Balloon Activity which directly engaged the participants to think spatially about the Universe expansion. The activity called for the participants to take careful measurements and looked at the spatial dimensions of the balloon as an expansion 3D model.

One of the questions in this study was ‘does curriculum explicitly rich in astronomic scale and cosmic spatiality influence learning of astronomy?’ The astronomy units were designed to help answer this question. The units were designed to offer high quality instruction for both experimental and comparison groups and were both grounded
in the national Benchmarks (AAAS, 2008). There was no intention in sacrificing the quality of education as a result this study. The intervention described served as the contextual basis as a pre and post intervention comparison between groups as part of this study as referred to in the following chapters.
CHAPTER 3

Preservice Elementary Teachers’ Conceptualization of Cosmic Dimensions

Title page

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Preservice elementary teachers’ conceptualization of cosmic dimensions

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Abstract

The purpose of this qualitative study was to explore preservice elementary teachers’ (n=70) conceptualization of cosmic dimensions (sizes, diameters, distances, orientations, and magnitudes). Pre and post interview data were gathered as part of a card sorting exercise designed to gauge how individuals utilize cognitive strategies to develop a personal cosmological description of astronomic dimensions. Results indicated that significant interpretations of astronomical principles were largely influenced by inaccurate perceptions of cosmological dimensions. Misconceptions of cosmic dimensions lead to naïve-theories comprised of both prior knowledge and the assimilation of new unfamiliar information. Participants lacked an astronomical vernacular in which to conceptualize and communicate accurate mental models of Space. Implications of these results within the context of preservice elementary teacher preparation are discussed.

Keywords Preservice elementary teachers; astronomy education; conceptual change; astronomy misconceptions; personal cosmology; preservice elementary teacher education; astronomical dimensions.

Preservice teachers enter teacher preparation programs with numerous previously construed misconceptions of science, and in particular, astronomy (Ashcroft & Courson, 2003; Trundle, Atwood, & Christopher, 2002; Abell, Martini, & George, 2001; Adams & Slater, 2000; Parker & Heywood, 1998; Atwood & Atwood, 1996; Novak, 1993). Previously construed misconceptions may be directly associated with the misunderstanding or inexperience with formal and in-formal science encounters throughout adolescence (Champagne, Gunstone, & Klopfer, 1985). For example, the ordering of the planets by successive distances may be a common activity within school science (Comins, 1998); yet fundamental misconceptions about the expanse of the Solar System may develop. The act of recalling planetary order may promote an inaccurate
linear model of the Solar System (i.e. all the planets are lined up in a line) with planets orbiting at equidistant concentric intervals from the Sun. This configuration of the Solar System represents a planetary arrangement which never exists in nature (NOAO, 1989). In reality, major planets orbit in near-circular paths around the Sun, which may cause planets to be much closer or further than typically thought. For example, the distances between planets may align on the same or opposite sides of the Sun (in reference to Earth) as represented in Figure 3-1.

![Figure 3-1: Orientations of non-linear planetary motions of Venus and Earth.](image)

When the average distances of planetary orbits are compared using the Sun as a reference point, the distances between outer planets are much larger than the distances between inner planets and all planetary distances are unequally spaced (NOAO, 1989). The distances between planets and their orbits are examples of cosmic planetary dimensions and may often times be misunderstood or unknown.

Cosmic dimensions describe the various astronomic scales of distances, diameters, magnitudes, and orientations of celestial objects and are frequently associated with enormous numbers. The colossal figures may prove to be problematic when preservice teachers attempt to formulate an accurate picture of celestial phenomena.
which may inhibit the learning of accurate astronomic information. For example, the
dwarf planet of Pluto may be thought of as drastically closer or further to the Earth when
equidistant-linear orbits are used as a Solar System model, which in turn may skew more
accurate distances to other planets. This model may fundamentally ‘shrink or expand’
one’s personal mental model of the Solar System due to inaccurate or unknown cosmic
dimensions.

In order to understand how preservice elementary teachers conceptualize scale
dimensions of Space, qualitative interviews were conducted to explore any relationship
between pre-existing misconceptions and cosmic dimensions associated with vast three-
dimensional scales of Space. Specific attention was placed on understanding how
preservice teachers’ mentally organized the vast scales associated with the
conceptualization of astronomic orientations. This article discusses the findings in order
to understand how preservice elementary teachers’ describe the cosmos and how the
conceptualization of Space influenced preservice teachers’ mental organizations of
astronomic information. In addition, this study explores conceptual change of astronomic
comprehension as a result of specially designed astronomy curriculum units administered
to two groups of preservice elementary teachers. Lastly, implications of these findings are
reported and discussed in order to help shape conceptual reform efforts within the context
of preservice elementary astronomy education.

3-2. Conceptual change as guiding framework

The misconceptions of astronomy among preservice elementary teachers need to
be corrected before they teach classrooms of children. Therefore, the identification and
repair of astronomic misunderstandings may occur when preservice teachers identify
their own misconceptions and reorganize astronomy information to be more consistent with scientific assumptions (Comins, 1998). Processing new with existing information may be considered one of the most effective strategies for science learning to occur (Merrill, Kelety, & Wilson, 2004) as our brains work toward a common goal of knowledge construction.

Piaget’s (1975) early work described the process of knowledge construction as equilibration. Equilibration described the process of developing new cognitive models by modifying existing ones. This learning model inferred that prior knowledge already existed and was considered essential for knowledge development to occur. Welmann and Gelman (1992) later contended that the modification of these pre-existing ideas may develop into naïve-theories when existing knowledge applied to new information resulted in a misconception. For example, the thought that summer temperatures were a result of the Earth’s proximity to the Sun may result from the organization of new information of orbital positions with existing ideas about heat sources. Pre-existing ideas about heat propagation may be well known based on years of personal experiences; therefore the learner may process contradictory information.

Chan, Burtis, & Bereiter (1997) suggested misconceptions develop into naïve-theories when the learner processes contradictory information when fitting new information (such as Earth’s elliptical orbit) with what was already known (such as the closer to a heat source, the hotter the temperature). The modified existing scientific information forms a basis of cognitive conflict in which a learner accepts or rejects (Limón, 2001) scientific information, independent of scientific accuracy. These decisions form the basis of a fundamental belief system which describes one’s personal view of the
scientific world. For example, the belief that Earth experiences summer when closer to the Sun during orbit has been found in children, college graduates, and adults (Schneps & Sadler, 1985) as well as preservice teachers (Trumper, 2001). The across-age and grade level results were evidence of the long-lasting influences deeply-rooted misconceptions may have on basic scientific information (i.e. the causation of Earth’s seasons). Deeply rooted misconceptions of scientific ideas may create impediments to the reorganization of information aligned with scientific assertions and must be repaired in order for deep understanding to occur (Chi & Roscoe, 2002; Vosniadou & Brewer, 1992).

These learning cognates were applied to astronomy education by Zeilik (2003) and Hufnagel (2002) who suggested sizeable benefits may result from the identification of pre-existing astronomic ideas when studying the Universe. Therefore, the identification of inaccurate pre-existing concepts of astronomy may be paramount to facilitate astronomical conceptual change and may be directly associated with individual perceptions’ of cosmic dimensions.

The use of individually constructed mental models may facilitate conceptual understanding of cosmic phenomena yet may be unique. Individuals may have their own personal perception of cosmic dimensions. The individual interpretations of cosmic dimensions may be central to the explanation of cosmological concepts and may be described as one’s “personal cosmology” (Comins, 1998, p. 119). Such personal cosmologies include dimensions associated with the origins, sizes, locations, motions, and ages of the Universe, Solar System, the Earth, and stars.

Unfamiliar or unknown cosmic dimensions may skew one’s mental description of accurate celestial relationships which may lead to the use of specific skill sets to manage
astronomical dimensions. The cognitive skill sets of astronomical scale and cosmic
spatiality may facilitate conceptual organization of astronomic information yet may
greatly vary among learners of astronomy. Wallace, Dickerson, and Hopkins (2007)
reported several differences among individual interpretations of scaled sizes and
distances of the Earth/Moon/Sun system.

If cosmic dimensions are unknown or unfamiliar, learners may make use of
metacognitive analyses in which to help model astronomical phenomena (Whitehead,
2007; Coll, 2005). The cognitive skills of scale perception (Tretter, Jones, Andre,
Negishi, Minogue, 2006) and cosmic spatiality (Rudmann, 2002) has been shown to
facilitate comprehension of science concepts associated with extreme dimensions and
may be applied to the development of a personal cosmology.

Restructuring astronomic misconceptions may be interconnected with particular
cognitive strategies used to organize information, such as the interpretation of cosmic
scales. Tretter et al. (2006) underscored the importance of scale perception as a leading
skill set which assisted the cognitive organization of more accurate science concepts at
the micro-scale. The cosmos exist within the three-dimensional volume of Space in
which vast scales may be applied. Therefore, the spatial relationships which interconnect
cosmic phenomena cannot be ignored. Rudmann (2002) accentuated the importance of
spatiality when learning concepts of astronomy due to the result of multiple interacting
cosmic factors. For example, the orbital inclination of the Moon and orbital distances
with respect to the Earth may be partially or non-observable or unknown by preservice
teachers. Inevitably, astronomic comprehension takes into account the ever changing
cosmic dimensions when applied to individual cognitive development of a personal
cosmology. Even simple concepts of astronomy are notoriously difficult for preservice teachers’ to understand since many ideas involve three-dimensional spatial positional relationships and scaled orientations between astronomical objects (Yu, 2005).

3-3. Concepts of astronomy and abstract dimensions

Astronomy is a unique area of science. Personal cosmologies may reinforce common misconceptions of familiar celestial neighbors, such as the Moon (Sadler, 1996), which perpetuate the manifestation of naïve-theories if lunar dimensions are unknown. The Moon’s orientation, phases and eclipses may be misunderstood if the lunar inclination with respect to the Earth (Figure 3-2) was not known or misunderstood. The angles of interest in Figure 3-2 utilize a double arrow scheme in which to illustrate the appropriate angle. The reason for this is in Space, the angle of measure must always be described by a specific frame of reference. For example, the Moon’s 5.15° inclination of orbit is represented with respect to Earth’s ecliptic plane by using two arrows across from each other. One arrow points to the imaginary line of Earth’s ecliptic plane (a) and the other to an imaginary line of lunar inclination (b) with respect to the Earth. For consistency, all degree measures are written across the top of the diagram.

Figure 3-2: Spatial representation of Earth/Moon system.

![Figure 3-2: Spatial representation of Earth/Moon system.](image)

Source: Planetary Science Research Discoveries/University of Hawaii Space Grant Consortium/NASA
Murphy and Bell (2005) identified the study of stars to be problematic for learners of astronomy due to the difficulties of ground-based observation and vast distances. The actual descriptions of star distances may be largely misunderstood (Dyche, McClurg, Stepans, & Veath, 1993; Phillips, 1991) due to the unfamiliarity of stellar dimensions and the concept of a light-year (Robertson, 2006). The lack of comprehension of stellar dimensions may leave learners without a meaningful framework of stellar dimensions in which to develop a personal cosmological model. The vastness of Space combined with the philosophical cloud surrounding astronomical concepts challenges current astronomy learners to develop astronomical models in order to facilitate astronomical conceptual change (Zeilik, Schau, Mattern, Hall, Teague, & Bisard, 1997).

Between relatively close celestial neighbors and more distant stars, the concept of cosmic dimensions may be problematic for learners of astronomy, including preservice teachers. Simply stated, Space is a place few have experienced which may make cognitive mental models of exotic dimensions difficult to formulate. The human mind has a very hard time conceptualizing extreme dimensions as our brains have evolved to make sense of the human-scaled world (Greene, 1999). The difficulty in conceptualizing cosmic dimensions may lead directly to misconceptions of basic astronomical phenomena. Although these astronomy misconceptions exist among preservice teachers and the minds difficulty with organizing astronomic dimensions, the subject cannot simply be ignored. Instead, this research attempted to understand how preservice elementary teachers conceptualize dimensions of Space in order to help shape the future teaching and learning of astronomy.
3-4. The choice of preservice elementary teachers

The choice to focus the present study on preservice elementary teachers was quite
deliberate. As mentioned earlier, much research has shown the abundance of astronomic
misconceptions among preservice elementary teachers. Many astronomy misconceptions
successfully bridge the teacher preparation graduation gap and were found rampant
among in-service elementary classroom teachers (Trumper, 2003; Barba & Rubba, 1992).
Inaccurate teacher beliefs about Space may significantly impact the inclusion of accurate
astronomy teaching in the elementary classroom (Schoon & Boone, 1997). Therefore,
preservice teachers prove to be a logical starting point for the future development of
qualified elementary science teachers.

3-5. Method

3-5.1 Participants

The participants in this study were preservice elementary teachers (n = 70)
enrolled in a required science content course as part of an elementary teacher preparation
program. The course design focused on National Science Education Standards (NRC,
1996) and Benchmarks for Science Literacy (AAAS, 2008) which included elementary
astronomy education standards. The two sections of the same course were used as
treatment (n = 37) and comparisons groups (n = 33) and were largely female (96.2
percent). Although designation of groups was arbitrary, the sample cannot be considered
random due to potential bias in selecting course section. Due to the relatively small
sample size, a census was utilized in order to obtain data from all participants. The
National Council of the Accreditation of Teacher Education (NCTE) accredited teacher
preparation program was specifically designed for future grade 1-6 teachers. Most
participants were traditional freshman (91 percent) and were mostly elementary education majors (88.5 percent). A few other majors such as business (1.3 percent), humanities (6.5 percent), sciences/engineering (2.6 percent), and other/no answer (1.3 percent) were represented among both groups. Typical ages of participants ranged from 18-21 years.

3.5.2 Astronomy unit overviews

The participants were administered two different variations of an astronomy unit based on elementary astronomy education standards (AAAS, 2008) which were grounded in Zeilik et al.’s (1997) assertion for a reduction of astronomy concepts among curriculum design. Therefore, the astronomy units consisted of seven astronomical subcategories which included astronomical scale, Sunlight intensity, seasonality, phases of the Moon, planetary orbit, scales of the Universe, and basic stellar properties. Each subcategory was underscored by the common themes of astronomic scale and cosmic spatiality yet was implemented differently in each section.

The treatment group’s astronomy unit was designed heavily around lessons and activities explicitly rich in astronomic scale and cosmic spatiality. The comparison group’s astronomy unit was based on traditional astronomy content (Straits & Wilke, 2003) which included implicit applications of astronomical scale and spatiality. Each unit included numerous pre-assessments as part of instruction in order to identify prior astronomical knowledge and was used to shape daily classroom discussions and interpretations of astronomical concepts. The astronomy lessons were portions of a general science content course for elementary education majors and were therefore held to only five weeks which totaled seven days of instruction.
3-5.3 Assessment instruments

3-5.3.1 The card sorting exercise and interviews

The participants were administered a modified version of Tretter et al.’s (2006) card sorting exercise (Appendix C) before and after the astronomy unit instruction. The modified card sorting exercise used 39 pictorial cards where participants were instructed to sort the cards into piles, thereby offering insight into the cognitive schema of celestial dimension differentiation. The 39 cards were samples which comprised a continuous range of sizes from the subatomic to the galactic. The modified measure was used to evaluate the preservice teachers’ general sense of scale. However, the added astronomy related cards were used to specifically focus on the organization of astronomy cards. The individual cards representative of cosmic dimensions associated to this study ranged from altitudes of Shuttle orbits to intergalactic distances as seen in Appendix C.

Immediately following the card sort exercise were qualitative interviews which allowed participants to describe their sorting rationale and descriptions of piles. Participants were allowed to think out loud and reorganize card piles as they wished during the interview process. Once the cards were sorted into piles of the participants’ choice, they were instructed to order the cards from smallest to largest within the piles and then arrange the piles in a line. Thereby a line of consecutively larger piles were ordered small to large to make an ordered scale of small to large with identifiable groupings (or discrete piles) of cards. This process allowed the researcher to better understand the participants’ conceptualization of cosmic dimensions.

The contextual framework of grounded theory (Glaser & Strauss, 1965) was used to explore how preservice teachers conceptualize cosmic dimensions. Open-interview questions allowed for flexible participant responses which were captured twice as part of
the pre and post quasi-experimental research design. The major interview question of interest was “can you please describe your thought process as you sorted the cards?” The question was deliberately open-ended which allowed participants to describe card sorting processes.

Active-listening (Bogdan & Biklen, 2007) and follow up probing questions were employed to help gather thick descriptions of participant responses. The documented interview responses were recorded via note-taking by the interviewer then first analyzed by open-coding which allowed for minute details of raw data to influence initial categories (Trochim, 2006) of common cosmic descriptions. Raw data analyses were conducted for each group of preservice teachers for both pre and post instruction interviews.

Once initial codes were established, data were axially-coded into a coding paradigm (Strauss & Corbin, 1990) following the logical progression of qualitative grounded theory research. This paradigm model was used to explain and expand strategic codes into more coherent themes of cosmic dimensions across the interviewees. A sample of qualitative coding paradigm can be found in Figure 3-3.

Figure 3-3: Sample coding paradigm.

<table>
<thead>
<tr>
<th>Participant responses:</th>
<th>Open-code:</th>
<th>Axial-code:</th>
</tr>
</thead>
<tbody>
<tr>
<td>“The space shuttle has been further than the moon.”</td>
<td>Shuttle distance</td>
<td>Unknown dimension: Manned space travel</td>
</tr>
<tr>
<td>“Some stars other than our sun reside within the solar system.”</td>
<td>Stellar distances Sun distance</td>
<td>Unknown dimension: Stellar distances Solar system: Mis-organization</td>
</tr>
<tr>
<td>“Sun is farther than a light year away.”</td>
<td>Light-year</td>
<td>Unknown dimension: Light-year</td>
</tr>
<tr>
<td>“Well I didn’t know what a light year was but it is really huge so I put it as the farthest card.”</td>
<td>Light-year</td>
<td>Unknown dimension: Light-year</td>
</tr>
<tr>
<td>“I am very familiar with Earth-based distances.”</td>
<td>Earth-based distance</td>
<td>Known dimensions: Earth continents</td>
</tr>
</tbody>
</table>
Coding paradigms where constructed and analyzed within and across groups for both pre and post instruction interview data sets.

In order to triangulate and support interview results (Boeije, 2002) the modified card sort exercises were quantified in order to identify any group shifts in themes as a result of the astronomy instruction. The card sort exercises were quantified by recording the participants’ order in which cards were sorted. For the extent of this research, only the space related cards are presented as part of this analysis. For example, if the participant indicated the distance from the Sun to Pluto (31) was the 30th card, than that particular participant’s card would receive a number assignment of 30. Participants’ collective card placements were averaged in order to establish an overall baseline of cosmic perceptions for each group before and after astronomy instruction. The averaging consisted of participant 1, 2, 3…nth placement of each card then divided by the total number of participants for each group. For example, participant one, participant two, and participant three, etc placed the altitude of the ISS card as cards number 20, 23, and 22…nth respectively in each of their piles. These numbers were then averaged. This strategy was used for all participants in each group for both pre and post astronomy intervention results. The correct order of card responses are listed in Figure 3-4 along with the pre and post averaged results of both comparison treatment and groups. The comparison was used to look for overall trends among the groups for both pre- and post astronomy instruction.
Figure 3-4: Averaged quantitative card sort data for pre and post test results

<table>
<thead>
<tr>
<th>Correct order and number of cards</th>
<th>Participants averaged responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Test Scores</td>
</tr>
<tr>
<td></td>
<td>Comp</td>
</tr>
<tr>
<td>18. Altitude the ISS</td>
<td>25.30</td>
</tr>
<tr>
<td>19. Distance to Space Shuttle Orbit</td>
<td>24.61</td>
</tr>
<tr>
<td>20. East-west distance of NY</td>
<td>19.39</td>
</tr>
<tr>
<td>21. Distance from Boston to LA</td>
<td>20.52</td>
</tr>
<tr>
<td>22. Distance from Syracuse to Sydney</td>
<td>21.70</td>
</tr>
<tr>
<td>23. Diameter of the Earth</td>
<td>25.45</td>
</tr>
<tr>
<td>25. Distance from Earth to the Moon</td>
<td>26.18</td>
</tr>
<tr>
<td>26. Distance of farthest manned Space exploration</td>
<td>27.21</td>
</tr>
<tr>
<td>27. Diameter of the Sun</td>
<td>27.70</td>
</tr>
<tr>
<td>28. Distance from Sun to Earth</td>
<td>29.55</td>
</tr>
<tr>
<td>29. Distance from Sun to Mars</td>
<td>30.70</td>
</tr>
<tr>
<td>30. Distance from Sun to Jupiter</td>
<td>31.21</td>
</tr>
<tr>
<td>31. Distance from Sun to Pluto</td>
<td>32.06</td>
</tr>
<tr>
<td>32. Distance from Earth to the edge of the Solar System</td>
<td>32.76</td>
</tr>
<tr>
<td>33. Distance of a light year</td>
<td>32.91</td>
</tr>
<tr>
<td>34. Distance from Earth to the nearest star</td>
<td>29.55</td>
</tr>
<tr>
<td>35. Distance from Earth to the North Star</td>
<td>30.12</td>
</tr>
<tr>
<td>36. Distance from Earth to the center of our galaxy</td>
<td>32.36</td>
</tr>
<tr>
<td>37. Distance across the Milky Way galaxy</td>
<td>32.82</td>
</tr>
<tr>
<td>38. Distance from Earth to the nearest galaxy</td>
<td>32.70</td>
</tr>
<tr>
<td>39. Distance from Earth to the farthest known galaxy</td>
<td>35.27</td>
</tr>
</tbody>
</table>

For example, the correct rank for the altitude of the ISS card among the eighteen Space related cards is 18. The average pre-test score for the placement of the altitude to the ISS card was 19.39 for the comparison group and 18.44 for the treatment group. After the astronomy interventions, the averaged group scores changed with the comparison group scoring 18.17 and treatment group scoring 18.06. The change between the pre and post scores is an example of a quantitative shift in overall group card placement to a more accurate relative position of the correct value for the altitude of the ISS card (18). These quantitative results are discussed in greater detail in the findings section of this paper.
The data analyses were used to inform and support emergent themes grounded in observational cases, such as the pre and post interviews and card sorting exercises. These qualitative and quantitative methodologies were used to describe the sample population’s description of cosmic dimensions and how they relate within the context of the social setting of preservice elementary teacher preparation.

3-6. Findings

The qualitative interviews revealed insight as to how preservice teachers’ conceptualized dimensions associated with astronomy. Major themes were uncovered through interview results and supported by quantitative data, as well as shifts in fundamental perceptions of astronomical phenomena. Sample participant quotes were selected as examples of commonly shared themes of card sorting criteria. Sample participant quotes were coded and assigned an arbitrary number to protect participant privacy. The sample participant quote coding schemes is as follows: Cpre- comparison group pre intervention, Tpre- treatment group pre intervention, Cpost- comparison group post intervention, and Tpost- treatment group post intervention. An arbitrarily assigned number was assigned to sample participants for data organization. For example, “Cpre21: I think Space is really cool!” represents a sample quote by participant 21 from the comparison group before the astronomy intervention.

The most prominently reoccurring theme described participants’ unknown perceptions of Space related phenomena. Forty-three of sixty-seven pre-astronomy instruction participants indicated that “Tpre36: I [they] had no clue about the Space cards and [were] totally guessing” with 37 percent rationalizing their sorting indecision by “CPre08: just put[ting] all the space cards in one pile.” Similar descriptions were
found when follow up questions asked to describe the Space card pile(s) with “CPre15: they are all like, really really big” and “CPre12: the space cards are just incomprehensible” being samples of the most common descriptions.

The major qualitative findings are presented and organized into themes which are supported by quantitative card sort results. The five major interview themes are presented in italics and labeled as Theme x.

Theme 1: Proximity of the International Space Station (ISS), Space Shuttle orbit and the Moon were misunderstood.

Space dimensions were applied to the description of man-made satellites and the location of the Moon. The altitude of the International Space Station (ISS) (18) and Space Shuttle (19) where typically placed just after Earth-based distances despite their relatively small vertical distances compared to Earth-based continental (horizontal) distances. The fact that the actual distance to the ISS is far smaller than the distance from Syracuse to Sydney or Boston to Los Angeles suggested a fundamental bias about distances associated with Space dimensions. This perception existed before the astronomy unit was taught which suggested a fundamental predisposition of cosmic dimensions as many participants explained similarly as, “Tpre12: I thought I was doing good until the space cards! I have no idea” and “Cpre04: I just gave up on space cards”. Although the Moon is the nearest celestial neighbor, many participants believed the Space Shuttle was capable of going to the Moon “Tpre19: the space shuttle can go to the Moon, right? How else did they get there?” and despite the Moon’s proximity participants expressed “Cpre33: the Moon is really far away!” Participants also associated the Space Shuttle
and ISS as “Cpre02: satellites” and indicated that satellites “Tpre16: float way out in space.”

Participants seemed to initially frame any Space related phenomena with extremely large scales which may add conceptual complexity as suggested by Tretter et al. (2006). The results are supported by quantitative card sort data which suggested 100 percent of all pre-astronomy instruction participants indicated that the distances to the ISS and Space shuttle to be larger than those of continental distances. The average placement of ISS and Space Shuttle cards for pre-astronomy instruction was 24.61 and 25.30, respectively, for the treatment group and 24.41 and 24.59, respectively, for the comparison group. These average scores are consistent with the qualitative findings and placed the altitudinal orbits of the ISS and Space Shuttle to be approximately near the Moon. The perception of near-Earth Space related phenomena may have been undermined by the predisposition of a biased contextual framework.

Interestingly, 100 percent of both post-instruction group scores indicated the altitudes to the ISS and Space Shuttle were still larger than continental distances on Earth. However, based on quantitative results a slight shift was found between the two groups. The comparison group averaged an ISS and Space Shuttle card placement of 25.29 and 24.91 respectively, which still placed the orbital positions near the Moon. The treatment group averaged an ISS and Space Shuttle card placement of 23.4 and 23.5 respectively, which placed the orbital positions equivalent to the diameter of Earth. One participant in the treatment group indicated that “Tpost11: the International Space Station (ISS) is much closer to the Earth than the Moon” while another claimed “Tpost20: most man-made stuff is really close to the Earth”. 
Although both post-instruction data results indicated anything in Space is larger than distances on Earth, there was a small shift in conceptualization of cosmic dimensions among the treatment group. The treatment group essentially reduced the cosmic dimensions associated with the ISS and Space Shuttle orbit about the Earth.

Theme 2: Over-estimation of manned-space exploration.

The perception of how far man has traveled into Space was found during the qualitative interviews from both groups before instruction. The common misconception may have been the product of an honest lack of known factual information of manned Space travel represented by such comments as “Cpre09: we [humans] have been to the Moon, but I have no idea where else they [astronauts] have been” and “Tpre13: you mean there are people in [S]pace right now?!”. Similarly, the assimilation of prior-experiences based on pop-culture may have led to partially known information about human Space exploration indicated by comments such as “Tpre19: we [humans] have been to Mars”, and “Cpre29: the space shuttle has been further than the Moon”.

Naive-theories of manned Space exploration may be a product of assimilating new with previously existing information. Either way, initial interviews revealed that manned Space exploration may encounter Solar System objects as far out as the outer planets, which may greatly underestimate the scale size of Solar System dimensions or the extent (and capabilities) of human Space exploration. Figure 3-5 shows the pre and post instruction limits of manned Space exploration by percentages of participants.
The perception of human Space exploration may conflict with the organization of astronomical dimensions when severe misunderstandings of manned missions exist. After the astronomy unit, perceptions of human Space travel significantly improved for both groups. The majority of participants seemed to conceptually understand the miniscule distances associated with manned Space exploration. "Cpost23: I know we [U.S. astronauts] went to the Moon and that it [Moon] is really far away" and "Cpost20: manned space travel has really only been as far as the Moon." Although a smaller percentage of post-instruction participants still indicated manned Space travel has been beyond the Moon, qualitative interview results have shifted to be more Moon-based although the accurate measure of the distance to the Moon may still have not been known. One participant expressed an extreme perspective as "Cpost11: the Moon is about half way from Earth to the Sun, so it’s probably near the North Star" but most common responses simply indicated “Tpost19: it [the Moon] is really far”.

Using the distance from Earth to the Moon as a reference point for the extent of manned Space exploration, 45.5 percent of comparison group pre-instruction indicated that manned Space exploration was beyond the Moon. Likewise, 55.9 percent of the treatment group pre-instruction responses indicated extra-lunar manned Space exploration.
Post-instruction results for both groups indicated a shift to smaller percentages of inaccurate manned Space exploration distances. The average treatment and comparison post-instruction card placements for the distance from Earth to the Moon (25), 25.86 and 24.97 respectively; and the extent of manned Space exploration (26), 26.86 and 26.49 respectively, represented a more accurate representation of these cosmic dimensions.

**Theme 3: Solar System compositions and dimensions were misunderstood.**

The Solar System, a topic commonly included among school science curricula, is often associated with the planets. Interview data suggested clear misunderstandings of numerous celestial objects that resided within the Solar System’s boundaries; which may lead to inaccurate scaled Solar System and star comprehension. In this case, the defined Solar System boundary would reach to the extent of the Sun’s major gravitational influence on Kuiper Belt objects and was represented as such on the Solar System distance card (32) card. During initial interviews, participants suggested stars (other than the Sun) were located within the defined boundaries of the Solar System as suggested by comments such as “Cpre11: some stars other than our Sun reside within the Solar System”, “Cpre33: the nearest star and North stars are within the Solar System, and “Tpre24: the North Star must be close cause [sic.] you can see it at night pretty good”. The common misconception about the proximity of stars (other than the Sun) to the Solar System (AIP, 1998) may be fundamentally grounded in inaccurate perceptions of stellar distances, Solar System distances, or both. The erroneous perceptions may obstruct the acceptance of a more accurate description of Space. Quantitative data reinforced these inaccurate cosmic dimensions and can be seen in Figure 3-6.
Even after astronomy instruction, the percentages indicated some participants believe stars reside within the boundaries of the Solar System as suggested by “post10: stars may still exist within the Solar System”. The average placement of the star distance cards shifted among both groups with the treatment group indicating more accurate card placement post-instruction. A positive shift in card placement indicated a larger conceptual position among ranked cards as compared to pre-instruction and can be seen in Figure 3-7.

The positive shift in card placements of stars indicated a mental ‘expansion’ of stellar distances with the largest shift (+3.22) associated with Proxima Centauri among the post-instruction treatment group. The negative shift in the placement of the distance from Earth to the Sun card among the comparison group (-1.52) mentally shrunk the card by approximately once and a half card placements smaller. However, although positive shifts occurred among both groups with regard to the distances to the stars other than our
Sun as a result of the astronomy instruction, many participants were still quite unsure how far stars really were and exclaimed “Post02: I’m not a scientist so I can’t figure out star distances”.

Fifteen percent of pre-instruction participants indicate that the expanse of the Solar System was the largest card among the piles and claimed, “Cpre30: the Solar System is the biggest card and has everything in it” as well as “Tpre06: there are other galaxies within our own Solar System”. However, the largest percentages of participants in each group indicated that the expanse of the (previously defined) Solar System was far beyond actual dimensions. Sixty-seven and seventy-five percent of pre-instruction comparison and treatment groups, respectively, indicated the distance from the Sun to the edge of the Solar System to be far too large. Likewise, eighty-eight and sixty-five percent of comparison and treatment groups respectively, indicated similar ideas during post-instruction card sort exercises. Many participants indicated that the expanse of the Solar System was larger than the distance from Earth to the center of the Milky Way galaxy as well as the distance across the entire Milky Way galaxy as seen in Figure 3-8.

Figure 3-8: Percentages of solar system expanse associated with galactic distances.

<table>
<thead>
<tr>
<th>Solar system expanse to include</th>
<th>Pre-instruction (%)</th>
<th>Post-instruction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Comparison</td>
<td>Treatment</td>
</tr>
<tr>
<td>Earth to center of Milky Way galaxy</td>
<td>36.3</td>
<td>36.4</td>
</tr>
<tr>
<td>Distance across the Milky Way galaxy</td>
<td>15.0</td>
<td>18.2</td>
</tr>
</tbody>
</table>

The inaccurate mental perceptions of stellar distances gave way to more accurate descriptions of planetary distances within the Solar System. The ordering of planet distances from the Sun outward was seen to be more accurate possible due to the common school activity of naming the planets in order. However, participants still
included the distances to stars within the defined boundaries of the Solar System.

Quantitative analysis used the averaged scores for each planet within each group before and after astronomy instruction. Figure 3-9 displays average scores of the distances from the Sun to the planets Earth, Mars, Jupiter, and Pluto (dwarf) for both groups pre and post astronomy instruction.

Figure 3-9: Average ordering of planets among groups across astronomy unit instruction.

<table>
<thead>
<tr>
<th>Pre-Comparison</th>
<th>Pre-Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.55</td>
<td>28. Distance from Sun to Earth</td>
</tr>
<tr>
<td>30.70</td>
<td>29. Distance from Sun to Mars</td>
</tr>
<tr>
<td>31.21</td>
<td>30. Distance from Sun to Jupiter</td>
</tr>
<tr>
<td>32.06</td>
<td>31. Distance from Sun to Pluto</td>
</tr>
<tr>
<td>30.12</td>
<td>35. Distance from Earth to North Star</td>
</tr>
<tr>
<td>29.55</td>
<td>34. Dist from Earth to the nearest star</td>
</tr>
<tr>
<td>32.76</td>
<td>32. Distance to the edge of the Solar System</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Post-Comparison</th>
<th>Post-Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.03</td>
<td>28. Distance from Sun to Earth</td>
</tr>
<tr>
<td>29.74</td>
<td>29. Distance from Sun to Mars</td>
</tr>
<tr>
<td>30.03</td>
<td>30. Distance from Sun to Jupiter</td>
</tr>
<tr>
<td>32.14</td>
<td>31. Distance from Sun to Pluto</td>
</tr>
<tr>
<td>30.86</td>
<td>35. Distance from Earth to the North Star</td>
</tr>
<tr>
<td>31.29</td>
<td>34. Dist from Earth to the nearest star</td>
</tr>
<tr>
<td>34.80</td>
<td>32. Distance to the edge of the Solar System</td>
</tr>
</tbody>
</table>

Included in the Figure 3-9 are the average placements of the collective planetary distances (in bold) for each group before and after instruction. The quantitative data suggested a fairly accurate mental representation of planetary bodies in the Solar System with an average score of 30.33 as many participants indicated “Tpost28: planetary distances are within the Solar System”. For comparison, the respective average scores for the cards placements associated with star distances and the distance to the edge of the Solar System are included in italics under each group’s data. The average group scores of stellar card placements were included to represent cognitive cosmic dimensional shifts of stellar distances. For example, the average placement of the distance from Earth to the
nearest star, Proxima Centauri, among the treatment group shifted from 29.38 before instruction to 32.60 after astronomy instruction. The mental perception of the distance from Earth to Proxima Centauri shifted +3.22 card placements among the treatment group, dramatically expanding the mental perception of star proximity among Space cards. Likewise, the comparison group expanded the mental perception of the distance from Earth to Proxima Centauri but only averaged a shift of +1.74 card placements. Only the post-astronomy instruction of the treatment group did the average proximity of star distances move to beyond Pluto, yet still resided within the Solar System as the average scores of star distance cards (32.60 and 32.94) were below the average score of the Solar System expanse card by the post treatment group (33.31).

Participants were asked to elaborate on their initial placement of planetary cards and the expanse of the Solar System. Participants indicated that “Cpre07: I thought the Earth to planet distance cards were more like Solar System cards” and “Tpre25: you can’t measure them [distances to the planets]”. Both groups seem to initially associate the Solar System with the known planetary bodies, which may be evidence from traditional school science activities, yet indicate their “Tpre03: inability to measure” the dimensions of the Solar System. This disconnect of cosmic dimensions may lead participants to be able to correctly identify common planetary bodies within an unknown expanse of Space, therefore leading participants to incorrectly include other celestial objects such as stars and galaxies within the Solar System.

The dimensions listed on the Space cards were described by many participants before the astronomy unit as “Tpre26: too big to visualize” or “Cpre08: unable to be measured”. Interview results found participants lacked a common language in which to
describe cosmic dimensions and indicated conventional everyday measuring techniques (and units) were not useful when applied to understanding Space. It is important to note that participants had a difficult time communicating the difference between the Solar System and a galaxy, and often used the words interchangeably. (The word ‘Universe’ was also used to describe extremely large entities.) This lack of vernacular acted as a barrier to conceptualization of the cosmic dimensions.

Post astronomy instruction interviews revealed cognitive development (albeit rudimentary) of coping strategies to associate astronomic dimensions. The development of a cosmic vernacular was part of the astronomy curriculum design as common language may facilitate scientific concepts associated with extreme scales (Tretter et al., 2006). Participants devised language which drew on relative descriptions among celestial entities such as “Cpost16: the diameters of celestial objects must be smaller than the distances between them” and “Tpost19: I tried to relate them [planet distances and diameters] relative to one another”. The expansion of strategies to handle cosmic dimensions facilitated conceptual understanding of basic astronomical phenomena. For example, the immense diameter of the Sun was described as “Tpost22: approximately one-hundred Earth diameters” and was used as part of astronomy instruction with each group.

Although the quantitative results indicated fairly consistent ordering of planetary distances across groups, qualitative interview codes for both groups resulted in a better strategy for communicating planetary distances. The main difference seen here is the ability to communicate the distances of planetary distances as well as rank them in correct order. The use of relative-ranking (Tretter et al., 2006) was expressed to help
describe enormous dimensions of the Solar System such as “Tpost32: I used the Earth and the Sun as reference points for establishing distances to other planets”, “Cpost11: It took like three days to get to the Moon, but I think it’s like six months to Mars”, and “Tpost12: the Moon is about 30 Earth diameters away”. The combination of quantitative and qualitative results suggested that on average the treatment group was able to better communicate a more accurate model of the Solar System after the astronomy instruction.

**Theme 4: The light-year was an unfamiliar unit for describing cosmic dimensions.**

The participants in both groups expressed a lack of familiarity with the astronomical distance of a light-year which was evident from frequent pre astronomy instruction interview comments analogous to “Cpre18: well I didn’t know what a light year was but it is really huge so I put it as the farthest card” and “Tpre07: I have no clue how far a light-year is”. The derived cosmic measure of distance was largely thought to be one of the largest cards within the entire card set however no presumptive justification was provided. Before astronomy instruction, the distance of a light-year card (33), described as a most unfamiliar of entity and was described by similar thoughts such as “Tpre11: I can’t really understand how far a light-year is”. The light-year was typically thought of an enormous distance associated with the measure of stars and galaxies as seen in Figures 3-10 and 3-11.

<table>
<thead>
<tr>
<th>Light-year as distance</th>
<th>Pre-instruction (%)</th>
<th>Post-instruction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>To the nearest star (Proxima Centauri)</td>
<td>27.3 30.3</td>
<td>24.2 24.3</td>
</tr>
<tr>
<td>From Earth to center of Milky Way galaxy</td>
<td>48.5 75.8</td>
<td>36.4 62.2</td>
</tr>
<tr>
<td>Distance across the Milky Way galaxy</td>
<td>36.6 48.5</td>
<td>27.3 35.1</td>
</tr>
<tr>
<td>The largest distance among the cards</td>
<td>27.3 30.3</td>
<td>24.2 35.1</td>
</tr>
</tbody>
</table>

Figure 3-10: Distances associated with the light-year for both groups before and after astronomy instruction.
Quantitative results from pre-instruction card sort data indicate that largest percentage of participants for both groups indicated the distance of the light-year was on the galactic scale with the average response indicating the light-year distance was beyond extended beyond the Milky Way galaxy. These results were consistent with the nature of perplexed interview responses when asked to provide justification for the placement of the light-year distance card. The light-year seemed to be conceptually unmotivated, which meant participants exerted very little effort to relate to such a dimension description and often ended in frank “Cpre16: I dunno [sic.]” type comments.

After astronomy instruction, the average placement of the light-year card among the comparison group dropped from the 38th to the 33rd of the 39 cards, or just beyond the edge of the Solar System which essentially conceptually ‘shrunk’ the distance of a light-year. However, many participants still expressed their complete unfamiliarity with the “Cpost14: cosmic tape-measure” by suggesting “Cpost18: I am still not sure about how far a light-year is”. Although the light-year was conceptually modified, the distance still resided beyond the closest stars which suggested stars are closer than one light-year.
away. The comparison group, on average, seemed to use the light-year as a boundary to define the outer edge of Solar System as indicated by the common interview response “Cpost30: all Solar System related cards were grouped then all others associated with a galaxy” and was indicated by average card placements. Galaxies seemed to take on the role as the largest objects in the Universe as many participants simply described “Cpost17: galaxies are huge!”

The treatment group, on average, did not seem to conceptually ‘shrink’ the distance light travels in one year as much as the comparison group. After astronomy instruction, the average placement of the light-year card among the treatment group dropped from the 38th to the 37th of the 39 cards, or just beyond the distance across the Milky Way galaxy. On average, the treatment group seemed to use the light-year as a boundary to define the outer edge of the Milky Way galaxy, rather than the Solar System. Yet previous results indicated the post-instruction treatment group formed a more accurate perception of Solar System dimensions. The fairly consistent placement of the light year card among treatment participants was slightly modified only by placement of galactic cards. The intra-Milky Way galactic distance remained constant at about one light-year before and after the astronomy instruction yet participants increased the inter-galactic dimensions between “Tpost05: the largest collections of objects [a galaxy] in Space”. This may suggest a clarification cosmic vernacular which clarified dimensions associated with different astronomical entities. The inconsistent results between both groups may suggest the conceptual difficulty of a light-year when preservice teachers think about cosmic dimensions.
**Theme 5: Earth-based dimensions are conceptually tangible.**

Participants were in unanimous agreement that comprehensions of Earth-based dimensions were much easier due to their familiarity of the Earth as common responses such as “Cpre14: I can understand continental sized distances by relating to flying on an airplane”, “Tpre09: I am very familiar with distances across the country”, and “Cpost18: I am very familiar with Earth-based distances”. The unfamiliarity of Space was used as comparison by many participants who explained “Tpost11: I have never been to Space”. The participants’ expressed their familiarity of Earth-based dimensions primarily due to the more familiar unit associations (i.e. miles other than light-years) suggested by “Tpost01: I know what miles are and how far things are apart like cities and stuff”, “Cpost06: I can drive to different states”, and “Tpost29: you can measure them [Earth-based distances]”. In addition, participants’ expressed their experience of intercontinental travel as a basis for comparison since many “Tpost19: I have been to California and Boston.”

Familiar experiences seemed to support the cognitive frameworks in which to think about global distances. Participants expressed conceptual dimensions as linear distances across the surface of the globe (such as the approximation of 3000 miles from Boston to Los Angeles). No major fundamental shift in conceptual comprehension occurred as a result of the astronomy curriculum as seen in Figure 3-12.
The apparent shifts in conceptual understanding of some astronomical dimensions were evidence that certain cosmic dimensions may serve as meaningful mechanisms in which to learn about Space. Reorganization of astronomical information may have been evident by the movement of celestial cards relative to one another among the 39 card sample. A more defined sense of celestial dimensions may serve as a conceptual framework in which to build a more accurate mental model of the cosmos. Preservice teachers may possess naïve-theories of more familiar known astronomical objects such as the Moon (Trundle et al., 2002) based on unfamiliar or unknown lunar dimensions.

Evolutionary speaking, human beings possess an innate ability to represent direct experiences of the physical and natural world as concepts (Pinker, 2002) and attempt to classify these concepts according to individually constructed mental models. Mental model generation may be a strategy used to conceptualize the celestial world yet is based on known and unfamiliar astronomic phenomena. Therefore, mental models are as only useful as they are accurate. Card sort interviews revealed discrete size ranges of celestial concepts which were used to create mental ‘pictures’ of Space but both pre and post instructional interviews may have been grounded in unfamiliar contexts, such as the distance of a light-year.

**Figure 3-12:** Earth-based land distances for both groups before and after astronomy instruction.

<table>
<thead>
<tr>
<th>Pre-Comparison</th>
<th>Pre-Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.52 21. Distance from Boston to LA</td>
<td>19.62 21. Distance from Boston to LA</td>
</tr>
<tr>
<td>21.70 22. Dist from Syracuse to Sydney</td>
<td>20.71 22. Dist from Syracuse to Sydney</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Post-Comparison</th>
<th>Post-Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.17 20. East-west distance of NY</td>
<td>18.06 20. East-west distance of NY</td>
</tr>
<tr>
<td>19.23 21. Distance from Boston to LA</td>
<td>19.69 21. Distance from Boston to LA</td>
</tr>
<tr>
<td>20.60 22. Dist from Syracuse to Sydney</td>
<td>20.83 22. Dist from Syracuse to Sydney</td>
</tr>
</tbody>
</table>

### 3.7. Discussion and conclusions

The apparent shifts in conceptual understanding of some astronomical dimensions were evidence that certain cosmic dimensions may serve as meaningful mechanisms in which to learn about Space. Reorganization of astronomical information may have been evident by the movement of celestial cards relative to one another among the 39 card sample. A more defined sense of celestial dimensions may serve as a conceptual framework in which to build a more accurate mental model of the cosmos. Preservice teachers may possess naïve-theories of more familiar known astronomical objects such as the Moon (Trundle et al., 2002) based on unfamiliar or unknown lunar dimensions.

Evolutionary speaking, human beings possess an innate ability to represent direct experiences of the physical and natural world as concepts (Pinker, 2002) and attempt to classify these concepts according to individually constructed mental models. Mental model generation may be a strategy used to conceptualize the celestial world yet is based on known and unfamiliar astronomic phenomena. Therefore, mental models are as only useful as they are accurate. Card sort interviews revealed discrete size ranges of celestial concepts which were used to create mental ‘pictures’ of Space but both pre and post instructional interviews may have been grounded in unfamiliar contexts, such as the distance of a light-year.
Pre and post data results suggested participants shared a concern for the lack of familiarity and inexperience with celestial distances, claiming there was “Tpre25: no way to measure them”. Human-beings are experienced with distances on Earth yet mainly exist in two-dimensions. Gibson’s (1979) early work suggested that meaningful events occur in relation or on surfaces in which we are accustomed. Although we live in a three-dimensional world, common descriptions of the physical environment are typically associated in linear dimensions, such as a football field as one-hundred yards or the distance between Boston and Los Angeles to be approximately 3000 miles. These linear distances may be modeled within the context of a horizontal plane (the ground), which can therefore be referenced to make comparisons of other dimensions. For example, the distance between Boston and Dallas may be approximately half that of Boston to Los Angeles. These comparative mental models may facilitate a more accurate model of the continental distances. This example was confirmed by interview results which indicated most participants’ familiarity with accurate continental distances and also correctly ranked all three Earth-based cards describing continental distances. However, Space leaves behind the familiarity of the two-dimensional plane as cosmic principles exist “Cpre10: up there”.

The conceptualization of vertical distances have been proven to be less developed in humans based on the world in which our brains have evolved to exist and survive (Zijiang & Nakayama, 1994). The determination of the actual distance of an overhead bird or sky scraper may be either misleading or incomprehensible, which resonated among participants’ descriptions of celestial phenomena. Just as a bird’s altitude may be difficult to determine, celestial entities which reside in vertical orientations coupled with
 extreme scale dimensions may prove to be “Cpre12: totally incomprehensible”. In fact, one participant indicated celestial dimensions “Tpost03: gave her a headache!” When asked about his concept of the Space exploration Hoyle (1979) commented, “Space isn't remote at all. It's only an hour's drive away, if your car could go straight upwards!”

The follow-up interviews uncovered some common scale anchors (Tretter et al., 2006) in which to conceptualize universal phenomena. A common reference point, unsurprisingly, was planet Earth. Both the ‘continental’ and ‘Solar System’ dimensions were referred to by participants Earth-centered. This held true for the Moon and manned Space explorations. The Solar System scale anchor was described by many as having to do with the planets yet there was discrepancy between the outer boundary of the Solar System and existence of stars. These scale anchors ‘concentrically’ extend beyond the Earth and Solar System to the stars, Milky Way, and galaxies beyond within an imaginary contextual framework gleaned from unfamiliar dimensions. These conceptual models of the Universe were identified by responses from post astronomy instruction interviews and provide insight into how preservice teachers’ conceptualize cosmic dimensions.

The use of common language was identified by Tretter et al. (2006) as an effective tool for understanding concepts associated with extreme scales. When applied to the vast astronomic scales, common language was used in lieu of exact metrics or unfamiliar dimensions. The fact that the light-year caused so much confusion among preservice teachers prompted the researcher to ponder the value of these units in the context of elementary teacher preparation. Georghiades (2000) recommended that learning science should involve discussions, thinking and writing tasks, and group
activities which allow learners to reflect on their own thinking using their own language. Preservice elementary teachers need to model and develop a casual astronomical vernacular in which to develop a well-constructed personal cosmology. Furthermore, providing preservice elementary teachers with the skills to teach astronomy may help them “explicitly and deliberately confront their learning processes while investigating astronomical content” (Bailey & Slater, 2007, p. 17).

3-8. Implications of study to teacher education

Findings from this study present three basic approaches to facilitating conceptual change of the cosmos among preservice elementary teachers. Based on these findings, the study showed:

1. *Preservice teachers’ construct individual mental ‘pictures’ of astronomical phenomena grounded in diverse perceptions of cosmic scale which need to be addressed as part of an astronomy education program. These individual mental pictures lead to misconceptions such as: over-estimation of manned Space travel; the existence of stars within the Solar System; unknown definitions and composition of Solar System/Universe; and the problematic concept of a light-year.*

2. *The huge Space related dimensions make Space related concepts indistinguishable. In other words, all Space related concepts are put under the category of “enormous” with little strategies for making distinctions of cosmic dimensions.*

3. *The development of a common vernacular including ratios, relative rankings, and qualitative definitions of celestial entities may greatly benefit the communication and organization of astronomical information associated with extreme cosmic dimensions.*
These findings suggest that there are certain strategies that are more effective for thinking about the huge dimensions of Space and that the initial thoughts of an inconceivable expanse can actually be thought of in a useful manner. Results from the present research study look to contribute to the collective body of recommendations for the advancement of preservice science teacher development within elementary astronomy education.
CHAPTER 4

The Interconnection between Preservice Elementary Teachers’ Perception of Scale and Spatial Aptitude when Learning Astronomy

Title page

Manuscript title: The interconnection between preservice elementary teachers’ perception of scale and spatial aptitude when learning astronomy

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The interconnection between preservice elementary teachers’ perception of scale and spatial aptitude when learning astronomy

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Abstract

The vast scales and spatial orientations of astronomical phenomena prompted the present study to investigate preservice elementary teachers’ (n = 77) perceptions of scale and spatial aptitude within the context of astronomy education. Results indicated highly correlated relationships between perceptions of scale and spatial aptitude which suggested that these two cognitive skill sets are interconnected. The present study also found moderate and high correlations between preservice teachers’ perception of scale, spatial aptitude, and astronomical comprehension which suggested that these interconnected skill sets may serve as necessary cognitive frameworks in which to think about and organize concepts of astronomy.

Keywords Preservice elementary teachers; astronomy education; cognitive skills, spatial aptitude, scale perception; preservice teacher education; astronomy, cosmic scales, astronomic distances.

Historically, the tradition of teaching and learning astronomy among young adults has been ill-equipped and has therefore considered being largely ill-taught in formal educational settings (McKinnon & Geissinger, 2002). However, the current resurgence of astronomy into the mainstream science curriculum has drawn attention to research efforts which call for a better understanding of the cognitive processes associated with learning astronomical processes (NRC, 2000). Central to this call is a focus on promoting scientific literacy by developing the language and cognitive skills sets necessary to facilitate effective science comprehension (Barab & Luehmann, 2003). The domain of astronomy is inherently based on concepts which call upon learners to engage cognitive skill sets which may aid the organization of information associated with the vast scales and spatial orientations of celestial processes at extreme scales. Such concepts often fall
prey to gross misconceptions of basic astronomy concepts and have been consistently found among preservice elementary teachers (Ashcroft & Courson, 2003; Trundle, Atwood, & Christopher, 2002; Abell, Maritni, & George, 2001).

The cognitive skill sets of scale and spatial aptitude have been shown to be an effective tool for understanding science (Tretter, Jones, Andre, Negishi, & Minogue, 2006; Rudmann, 2006; Black, 2005) but no research to date has explored any relationship between them within the context of astronomy education; specifically, among preservice elementary teachers. The present study explored the two specific cognitive skill sets of scale perception and spatial aptitude within the context of astronomy education among preservice elementary teachers; as well as inform alternative instruction to traditional astronomy education which may help develop cognitive skills necessary for astronomical comprehension (Hollingworth & McLoughlin, 2001).

4-2. *Theoretical framework of cognitive skill sets*

4-2.1 *Scale*

Scaling concepts have been identified as one of the important unifying themes and is closely associated with the “effect of size on properties, variety of magnitudes in nature, and description of extremes” (AAAS, 2007, p.98). The scales associated with astronomy may be quite exotic and difficult for the human brain to comprehend (Black, 2005; Greene, 1999). Current science education literature addresses this concept of extreme scales and the difficulty of “appreciating phenomena which involved magnitudes far removed from human experiences” (AAAS, 2007, p. 98) such as astronomical metrics. Few studies have been conducted on the implications of scale and human cognition when learning science. Dyche, Mcclurg, Stephans, & Veath, (1993) found
students’ had difficulty mentally identifying stellar distances when asked to apply astronomical data to physical models while Skamp (1998) observed that students typically have problems understanding the scales and distances of Space in general. Some excellent research conducted by Tretter, Jones, Andre, Negishi, & Minogue (2006) on the conceptualization of the scale of scientific phenomena indicated that relative size information was more readily understood than exact size as well as a high correlation between scale conceptualization and academic level of science comprehension. This work emphasized the importance of scaling efforts as they apply to the microscopic realm. Trend (2001) applied the concept of scale to the concept of Deep Time in geoscience education and found that elementary teachers have vague criteria for defining geologic history. Trend (2001) reported elementary teachers preferred “to cluster” (p.209) the temporal order of significant geologic events without knowing the exact numeric geologic records. Although the concept of Deep Time is closely associated with concepts of astronomy, “no relevant research” (AAAS, 2007, p.98) has been conducted to understand how the cognitive understanding of scale is associated with learning astronomical concepts; concepts which are inherently connected with limitless metrics.

4-2.2 Spatiality

Spatial aptitude has been defined as the ability to represent, transform, generate, and recall symbolic, nonlinguistic information (Linn & Peterson, 1985). In other words, spatial aptitude describes the mental ability to interpret, manipulate, and make sense of the three dimensional physical Universe and has been identified as a skill set which may facilitate the learning of scientific information (Chadwick, 1977). Much research has been dedicated to analyzing and understanding human spatial aptitude (Orion, Ben-Chaim, & Kali, 1997). Many research studies have focused on how spatial aptitude
facilitated success in science including: physics (Palrahd & Seeber, 1984); Earth science (Black, 2005; Piburn, Reynolds, Leedy, McAuliffe, Birk, & Johnson, 2002; Chadwick, 1977; chemistry (Jones, Bokinski, Tretter, Negishi, Kubasko, Superfine, & Taylor, 2003); and astronomy (Rudmann, 2002). Other research indicated how inaccurate spatial models of celestial systems can lead to misconceptions of basic astronomical concepts (Brewer & Rudmann, 2002). Furthermore, research also suggested that some science courses have been shown to increase spatial aptitude over time (year-long courses) (Bodner & Guay, 1997; Orion, et al., 1997). The abundance of related literature strongly suggests that spatial aptitude is a cognitive factor linked to high performance in science (Lord & Rupert, 1995). Specifically, when applied to the seemingly abstract domain of astronomy, Rudmann (2002) suggested that in order for learners to better understand and apply scientific explanations of astronomy, it is necessary to provide spatial skills training as a component of instruction.

4-3. Contextual basis of cognitive skill sets

4-3.1 Contexts of scale within astronomy

Humans do not encounter scientific concepts associated with extreme scales in everyday life; yet the concepts of scale do not simply imply the idea of knowing exact dimensional metrics (i.e. size, weight, length, temperature, etc.). For example, people may not know the familiar Empire State Building in New York City is exactly 1,250 feet tall. But most will know that the building is taller than a traditional house. Instead, concepts of scale can be applied to specific contexts outlined by Tretter et al. (2006) as (a) the relative scales and sizes of dimensions are often expressed using common language in order to describe our environment. People use everyday language like larger-
than or smaller-than to describe objects/systems and are less concerned with nominal metrics. Everyday uses of and conceptions of size are usually satisfied with “categorical relations and unconcerned with precise numbers” (p. 305). (b) Scale can also be associated with proportions, or “approximate ratios” (p. 286) when describing scientific phenomena. The extreme distance from the Sun to Pluto is not an everyday value. In this context, the relative distance from Earth to Pluto about 40 times the distance from the Sun as Earth, as opposed to 4 times or 4000 times. Trend (2001) argues scale used in this context can be beneficial when learning geologic time and therefore we extend this argument to include astronomical concepts. (c) Properties in nature can be “scale specific” (p. 287) such as the gravitational forces between celestial objects described by the inverse square functions of scaled masses and distances. The orientation of celestial objects amid vast scales can play an important role in understanding astronomical phenomena and temporal events.

4-3.2 Contexts of spatiality within astronomy

Many concepts of astronomy are directly linked to spatial orientations of various celestial systems and since most humans have never traveled into Space, cognitive skills are employed to create mental models of the three dimensional existence of celestial objects and events. For this reason, spatial aptitude becomes a valuable skill when learning astronomical concepts. Various perspectives must be considered in order to describe the cosmos by establishing observational frames of reference. Since the frames of reference may be from various perspectives, there may be controversy over the conclusions of cosmic spatial relationships and events. Taylor and Tversky (1996) asserted that reference frames may include: (a) a known or fixed origin, (b) a coordinate
system, (c) a certain position of view in terms of reference points, and (d) a referenced object or set of objects. Either way one establishes the reference frame, spatial descriptions contain statements that locate objects with respect to a frame of reference or specific relative position. In order to resolve controversies, Levinson (1996) suggested that the reference frames of observation must be identified when describing any spatial orientation. For example, observing the Sun set at dusk may be interpreted as two different scenarios: (1) the Sun is fixed in the sky and only appears to move toward the horizon as the Earth rotates away; or (2) the Earth is fixed (presumably as we are fixed to the Earth) and the Sun appears to moving across the sky toward the horizon during Sunset (a more common social interpretation of a Sunset). Either interpretation may be acceptable as long as the observer clearly defines the reference point of apparent motion (albeit two observers may describe the same apparent geo-helio motion differently). As noted earlier, most humans will only possess one frame of reference, as most of us have never been to Space.

Thus, our frame of reference must be one of outward gaze (Ehrich and Koster, 1983) or thinking about the Universe with respect to our miniscule realm while keeping a fixed origin of observation (Earth-based). This spatial mental model may cause misconceptions when describing the apparent position of the Moon each night, from our fixed point on Earth. The true lunar orbit about the Earth may not be well represented by direct observation from Earth. Therefore, a route tour model (Levelt, 1982a) may be useful when trying to ‘imagine’ how celestial bodies are spatially located. This model required an observation of moving origin but the lack of direct experience in Space may provide some barriers. A route tour described a model which connected the act of mental
simulation, such as trying to understand (or imagine) planetary orbits by thinking of oneself from a vantage point above the planetary ecliptic planes, and ‘looking down’. Such spatial mental models may be translated into graphical representations which may lead to the reinforcement of common misconceptions such as highly elliptical (or exaggerated) planetary orbits. In addition, the scale magnitudes associated with spatial mental model construction may add to the complexity of accurate astronomical comprehension. Klein (1982) suggested either of these mental models were a matter of cognitive preference and equally valid as long as the model was based on accurate scientific information.

4-4. The study

The vast scales and spatial orientations of astronomical phenomena prompted the present study to investigate preservice elementary teachers’ perceptions of scale and spatial aptitude within the context of astronomy comprehension. The present study compared baseline measures of preservice teachers’ perception of scale and spatial aptitude with performance on astronomy knowledge measures. The study hypothesized that preservice elementary teachers’ perceptions of scale and spatial aptitude were interconnected cognitive skill sets which help predict astronomy comprehension. The target dependent variable was basic astronomical comprehension with perception of scale and spatial aptitude as independent variables. Therefore, the present study was not designed to promote cognitive skill development simply due to the temporal nature of the research design. Essentially, this research study attempted to answer the following question: Do perceptions of scale and spatial aptitude play a role when preservice elementary teachers’ learn basic concepts of astronomy?
4-5. Methodology

4-5.1 Participants

The participants in this study (n = 77) are enrolled in an elementary teacher preparation program and are interested in becoming future elementary teachers grade 1-6. The participants were selected based on their desire to become elementary teachers and due to the sample size a census was utilized to obtain data from all participants. Therefore strategic sampling was not an issue and the sample cannot be considered random due to a bias in selecting course section. The sample populations were enrolled in one of two sections of a science content course specifically developed for preservice elementary teachers. The course was designed to provide future elementary teachers an opportunity to learn accurate fundamentals of science outlined by the national benchmarks and state standards for elementary science education. The two-semester course sequence focused on concepts of physical science which included a component of astronomy. The sample population was utilized during the five-week astronomy component of the required science content course. The sample population was largely first-year students (94 percent) with a few upper class students and was typically 18-21 years of age. Aside from the few upper class participants less than five percent of first-year participants indicated they have taken formalized astronomy courses prior to enrolling in the teacher preparation program. This study took place in the northeastern United States during the fall semester; which was most participants first semester of collegiate level instruction.

4-5.2 Assessment instruments

In order to assess preservice teachers’ perceptions of scale, the Scale of Objects Questionnaire (SOQ) (see Tretter et al, 2006) [Appendix B] and an adapted version of
Tretter’s et al. (2006) Card Sort Activity [Appendix C] were administered. The Scale of Objects Questionnaire (SOQ) was a 26 item-matrix with a choice of selectable size ranges and was used to determine baseline perceptions of scale. In order to score this SOQ, responses were given one point for a correct response and zero for an incorrect response. Due to the nature of some of the SOQ items, two size ranges were deemed acceptable, which is a slight alteration from the original coding scheme. These dual-response items were identified due to the arbitrary size range box selection based on personal experience. The total number of correct responses was tallied. The higher the number, the better an individual performed on the SOQ.

The modified Card Sort Activity included a set of 39 cards which emphasized item descriptions across a continuous scale, with the addition of numerous astronomical concept cards, and was used to help triangulate participants’ perceptions of scale. The Card Sort Activity was scored by computing the absolute value of the difference between the participant and the actual rank score. For example, if the participant ranked a card as being the fourth in the continuous list and it should have been third, than the calculated value for that card item would be 1. The larger the absolute value number calculated, the farther off the participant ranked the card from the actual rank. In order to convert Card Sort Activity scores into coding schemes consistent with all other measures, the total summed number of absolute value scores were then subtracted from 760 (760-x). 760 was calculated by taking the complete wrong ordering of cards, which would yield 760, making this the perfect score by subtracting the tallied score from 760. In this coding scheme, zero, was now the worst possible score, with 760 being perfect. Therefore, this coding scheme transposed to the higher the number, the better the score on the Card Sort
Activity. The Card Sort Activity included qualitative interviews following the exercise which helped describe the thought processes of individual cognitive sorting schemas. The findings from in-depth analyses of the qualitative interviews can be found in Chapter 3 of this dissertation.

The Purdue Visualizations of Rotations Test (ROT) was administered (see Bodner & Guay, 1997) [Appendix D] in order to assess the spatial aptitude of the sample population. The ROT was employed in the present study given the three-dimensional nature of test items which more closely aligned with the three-dimensional physical setting. In accordance with the measures design, the ROT was administered with a strict time limit in order to reduce analytical reasoning. In order to assess preservice teachers’ ideas about astronomy, the nationally validated Astronomy Diagnostic Test 2.0 (ADT) was administered (see Hufnagel, 2002) [Appendix E]. This version of the ADT targeted one astronomical concept per question as well as fostered a battery of 21 astronomic test items which were closely associated with concepts of cosmic scale and spatiality.

4-5.3 Astronomy unit overviews

The two astronomy curricula were based on literature which suggested proven strategies for more effective practices of astronomy education. Zeilik et al. (1997) demonstrated astronomy curriculum with no more than ten interconnected astronomical concepts were more effective at correcting misconceptions and re-learning accurate astronomy concepts. Therefore, the astronomy curricula were designed to include the same seven astronomical concepts (as a result of conceptual reduction), yet the lessons and activities used varied by section. The seven astronomical curricular subcategories were astronomical scale, Sunlight intensity, seasons, the Moon, the Solar System, scales
of the Universe, and the stars. Each lesson shared the common themes of astronomical scale and cosmic spatiality.

The main differences between the treatment and comparison groups were the respective astronomy curricula. The treatment group received lessons and activities explicitly associated with concepts of astronomic scale and cosmic spatiality whereas the comparison group received a more traditional astronomy curriculum as outlined by Yore (1991). Each group completed numerous pre-assessments as part of instruction in order to identify prior astronomical knowledge and used to shape daily classroom discussions and interpretations of astronomical concepts. The astronomy curricula were portions of each section’s (experimental or comparison) overall science content course for elementary education majors and were therefore held to only five weeks which totaled seven days of instruction.

4-6. Results

4-6.1 Interconnected skill sets

Preliminary results indicated that all variable pretests were normally distributed in the sample population (skewness and kurtosis between +/- 1), with the exception of the Card Sort Pretest and Posttest (SKEW_{CardSortPretest} = -1.107; SKEW_{CardSortPosttest} = 1.379), respectively. However, these values resided within the acceptable range of +/- 2 for psychometric research (University of Illinois, 2008) and were subjected to parametric statistical analysis due to the robust nature of the t test (Sprinthall, 2003). The means and standard deviations of the continuous variables can be seen in Table 4-1.
Two assessments were utilized in order to assess the preservice teachers’ perceptions of scale, the SOQ and the Card Sort Activity. In order to check for consistency across these two related measures, a (Pearson’s) correlation test was conducted and analysis showed a highly significant positive correlation ($r^2 = .445 \ p < .01$); which suggested that those who achieved a higher score on the SOQ also scored better on the Card Sort activity. Next, a (Pearson’s) correlation test was conducted to determine the relationship between scores of scale perception (SOQ, Card Sort) and scores of spatial aptitudes (ROT). High and significant correlations were found between preservice teachers’ perception of scale and spatial aptitude as indicated by the obtained results on administered measures and can be found in Table 4-2.

Table 4-1: Means and standard deviations/error (in parenthesis) within section and in overall sample.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADT Pretest</td>
<td>70</td>
<td>5.90 (1.897)</td>
<td>.279 (.287)</td>
<td>-.267 (.560)</td>
</tr>
<tr>
<td>ADT Posttest</td>
<td>70</td>
<td>7.13 (2.401)</td>
<td>.413 (.287)</td>
<td>.492 (.566)</td>
</tr>
<tr>
<td>SOQ Pretest</td>
<td>77</td>
<td>12.26 (4.402)</td>
<td>-.659 (.274)</td>
<td>-.048 (.541)</td>
</tr>
<tr>
<td>SOQ Posttest</td>
<td>67</td>
<td>12.94 (3.837)</td>
<td>-.872 (.293)</td>
<td>.936 (.578)</td>
</tr>
<tr>
<td>ROT Pretest</td>
<td>77</td>
<td>10.57 (1.897)</td>
<td>-.115 (.274)</td>
<td>-.885 (.541)</td>
</tr>
<tr>
<td>ROT Posttest</td>
<td>77</td>
<td>10.11 (4.131)</td>
<td>-.208 (.274)</td>
<td>-.713 (.541)</td>
</tr>
<tr>
<td>Card Sort Pretest</td>
<td>66</td>
<td>650.44 (61.197)</td>
<td>-1.107 (.295)</td>
<td>.708 (.582)</td>
</tr>
<tr>
<td>Card Sort Posttest</td>
<td>63</td>
<td>677.94 (50.633)</td>
<td>-1.332 (.302)</td>
<td>1.379 (.595)</td>
</tr>
</tbody>
</table>
These results showed those who performed better on the SOQ Pretest and Card Sort Pretest also scored better on the ROT Pretest which suggested those with a better sense of scale perception showed a more advanced spatial aptitude. A Pearson (r) correlation was computed between scores on SOQ Pretest, ROT Pretest, and ADT Pretest in order to explore if there was any correlation between initial understanding of astronomy and cognitive skill sets. As expected, there indicated no significant correlation between the three variables as a comparison of baseline measures. After the astronomy unit was implemented, post tests were administered to look for relationships between variables. Moderate and high positive correlations were found between baseline measures (pretests) of SOQ, Card Sort Activity, ROT and both ADT Posttest and ∆ADT scores as seen in Table 4-2. Significant linear correlations were found among variables which concluded that those who achieved higher scores of either scale perception, spatial aptitude or both achieved higher gains in astronomical comprehension. This finding reinforces the strong interconnection between the suggested skills sets which facilitate astronomy learning.

<table>
<thead>
<tr>
<th></th>
<th>Card Sort pre</th>
<th>SOQ pre</th>
<th>ROT pre</th>
<th>∆ADT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Card Sort pre</td>
<td>1.000</td>
<td>.445**</td>
<td>.300*</td>
<td>.295*</td>
</tr>
<tr>
<td></td>
<td>---</td>
<td>.000</td>
<td>.014</td>
<td>.020</td>
</tr>
<tr>
<td>SOQ Pre</td>
<td>1.000</td>
<td>.439**</td>
<td>.262*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>---</td>
<td>.000</td>
<td>.029</td>
<td></td>
</tr>
<tr>
<td>ROT Pre</td>
<td>1.000</td>
<td>.367**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>---</td>
<td>.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>∆ADT</td>
<td></td>
<td></td>
<td>1.000</td>
<td></td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (two-tailed).
* Correlation is significant at the 0.05 level (two-tailed).
Since both cognitive skills sets demonstrated significant influences on astronomical comprehension, statistical tests were employed to analyze cognitive skill development as a result of the astronomical unit. This manipulation check controlled for any cognitive skill gains which may have influenced astronomical comprehension scores (Kazdin, 2007). Highly significant correlations existed between Card Sort Activity Pre-Posttests ($r^2 = .558 \ p < .01$), ROT pre-posttests ($r^2 = .768 \ p < .01$), SOQ pre-posttests ($r^2 = .705 \ p < .01$), and ADT pre-posttests ($r^2 = .289 \ p < .05$). These positive correlations suggested those that scored higher on specific pretests also scored higher on corresponding posttests. However, in order to determine whether these highly correlated scores were of statistical significance, paired-samples $t$ tests were computed (George & Mallory, 2007) between pre- and post-test scores of SOQ ($t(66) = -1.949, \ p > .05$) and ROT ($t(76) = 1.399, \ p > .05$). The null hypothesis could not be rejected and it was concluded that there was no significant difference between SOQ and ROT pre- and posttest scores (Sprinthall, 2003) which suggested no evidence of spatial aptitude or scalar development as a result of the astronomy unit.

The Card Sort Activity showed a statistical difference between the pre- and post-test scores ($t(56) = -3.923, \ p < .01$) but may be explained by the nature of the exercise. Only the Card Sort Activity allowed participants to think, reflect on, and change their actions during the exercise via a post activity interviews and a test-retest effect may have influenced results, especially as a product of the astronomy unit. Also, since the Card Sort Activity was implemented as an out of class appointment, loss of data resulted in a lowered sample size. However, as mentioned earlier, the strong positive correlation was consistent with results of the other measures.
A paired-sample *t* test was computed which compared pre- and posttest scores of astronomical comprehension (ADT) and were found to be statistically different (*t*(69) = -3.962, *p* < .01) which suggested posttest scores were significantly better than pretest scores for both groups. Further analyses were conducted to understand how statistically higher posttest scores translated into astronomical comprehension and therefore, gain scores were computed (ΔADT) in order to control for prior cosmic knowledge. Astronomical gain scores were then correlated with baseline measures (pretests) of perception of scale (SOQ and Card Sort Activity) and spatial aptitude (ROT). Pearson’s tests were conducted and analyses showed moderate and high correlations between ΔADT and Card Sort Activity pretest (*r*² = .295 *p* < .05), SOQ pretest (*r*² = .262 *p* < .05), and ROT pretest (*r*² = .367 .295 *p* < .01) and can be seen on Table 4-2. These results showed that those who demonstrated higher gain scores of astronomical comprehension also showed higher baseline skills of scale perception and spatial aptitude which suggested these cognitive skill sets may be closely associated with the learning of basic cosmic concepts.

4-6.2 Between group comparison

Preliminary results indicated that the continuous computed dependent variable-ΔADT (computed as ADT<sub>Posttest</sub>-ADT<sub>Pretest</sub>) was normally distributed in the sample and within both experimental and comparison groups (skewness and kurtosis between +/- 1), with the exception of the comparison group ADT Posttest(KUR<sub>ADTPostComp</sub> = -1.293). However, this value resided within the acceptable range of +/- 2 for psychometric research (University of Illinois, 2008). The means and standard deviations of the continuous variables can be seen in Table 4-3.
Participants in the comparison group had a higher mean ADT pretest score than those in the experimental group. A two-sample independent \( t \) test was computed to compare normality and distribution of baseline ADT Pretest scores between the two groups. Results were not found to be significant (\( t(68) = -0.817, p > .05 \)). Additionally, Levene’s test indicated equal variances (\( F(1,68) = 0.270, p > .05 \)) between the two sections with regards to ADT Pretests (Sprinthall, 2003). The null hypothesis could not be rejected and it was concluded that there was no significant difference between ADT Pretest scores, which suggested homogenous baseline measures of astronomical comprehension for both sections. In contrast, the differences between the two groups in ADT Posttest and \( \Delta \)ADT were significant (\( t(68) = 2.762, p < .05 \)) and (\( t(68) = 3.244, p < .05 \)), respectively. The null hypothesis therefore was rejected which suggested the mean scores for each group were statistically different, with the experimental group mean score higher than the comparison group mean score. Levene’s test indicated equal variances were found between ADT Posttest (\( F(1,68) = 1.127, p = .723 \)) and \( \Delta \)ADT (\( F(1,68) = 1.826, p = .181 \)) scores as well.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Comparison (N = 33)</th>
<th>Treatment (N = 35)</th>
<th>Overall (N= 68)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest ADT</td>
<td>6.09 (1.991)</td>
<td>5.71 (1.808)</td>
<td>5.90 (1.897)</td>
</tr>
<tr>
<td>Posttest ADT</td>
<td>6.37 (2.340)</td>
<td>7.89 (2.246)</td>
<td>7.13 (2.401)</td>
</tr>
<tr>
<td>( \Delta )ADT</td>
<td>0.286 (2.573)</td>
<td>2.17 (2.281)</td>
<td>1.229 (2.594)</td>
</tr>
<tr>
<td>SOQ Pretest</td>
<td>11.0 (4.787)</td>
<td>13.49 (3.648)</td>
<td>12.26 (4.402)</td>
</tr>
<tr>
<td>Card Sort Pretest</td>
<td>637.06 (63.902)</td>
<td>662.29 (57.00)</td>
<td>650.44 (61.197)</td>
</tr>
</tbody>
</table>
Following the logic of $t$ test statistics, a significant difference led to the calculation of the effect size correlation in order to determine the strength of significant difference between the two sections. Cohen’s $d$ (1977) was computed ($d = 0.78$) which suggested the intervention had a strong effect on the astronomy knowledge of participants in the experimental section. Cohen (1988) related effect size in terms of the percent of non-overlap of the experimental group's scores with those of the comparison group. An “effect size of 0.8 indicates a non-overlap of 47.4% in the two distributions” (Cohen, 1988, p. 21-23). Wolf (1986) suggested an effect size ($d = 0.78$) which fell above .50 suggested a clinical result (e.g. something really changed).

This study concentrated on only one dependent variable (∆ADT) with various independent variables and therefore utilized multiple regressions for analysis. The independent variables of analyses in this study were spatial aptitude (ROT) and scale perception (SOQ and Card Sort). Statistical analyses were computed using SPSS 16.0 to explore the relationships between the independent variables and their influences on astronomical comprehension. In order to establish baseline measures of each sections’ perceptions of scale and spatial aptitudes, two-sample independent $t$ tests were computed between each group to check for significant differences. Results indicated that there was no significant difference between SOQ ($t(59) = 1.531 \ p > .05$), Card Sort ($t(59) = 1.560, \ p > .05$) and ROT ($t(59) = .713, \ p > .05$) Pretests. Levene’s tests indicated equal variances between the two sections of SOQ, Card Sort, and ROT Pretests ($F(1,59) = .818, \ p = .055), (F(1,59) = 1.835, \ p = .181), (F(1,59) = .204, \ p = .653$) respectively. The null hypothesis could not be rejected and it was concluded that there were no significant
differences between SOQ, Card Sort, and ROT Pretest scores which suggested homogenous baseline measures of scale perception and spatial aptitude for both sections.

Special interest focused on exploring any differences of astronomy comprehension between each section as a result of each particular astronomy curriculum (experimental vs. traditional). In order to analyze any significant difference, a dummy variable which denoted Section (experimental or comparison) was entered into multiple regression analyses. Multiple linear correlations were computed to predict ∆ADT scores from Section, SOQ, Card Sort, and ROT Pretests. The multiple $R$ was found to be .473, and was significant ($F(2,59) = 8.502, p = .001$). The linear combination of Section, SOQ, Card Sort, and ROT Pretests were shown to be predictors of ∆ADT scores. However, only Section ($t(59) = 2.606, p < .05$) and ROT Pretest ($t(59) = 2.611, p < .05$) were highly significant independent variables. More specifically, ROT Pretest accounted for 13.4% percent of the variability on ∆ADT scores while Section (experimental or comparison) accounted for an additional 8.9%, which yielded a total of 22.4% of the variance in ∆ADT scores as seen in Table 4-4.

Table 4-4: Model summary for ROT Pretest scores and Section.

<table>
<thead>
<tr>
<th>Between group</th>
<th>$R$</th>
<th>$R^2$</th>
<th>Adjusted $R^2$</th>
<th>Std. Error of Estimate</th>
<th>$R^2$ Change</th>
<th>$F$ Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROT Posttest</td>
<td>.367</td>
<td>.134</td>
<td>.126</td>
<td>2.433</td>
<td>.134</td>
<td>9.312</td>
</tr>
<tr>
<td>Section</td>
<td>.473</td>
<td>.224</td>
<td>.197</td>
<td>2.324</td>
<td>.089</td>
<td>6.792</td>
</tr>
</tbody>
</table>

Total $N= 77$
Dependent variable: ∆ADT
Excluded variables: SOQ Pretest, Card Sort Pretest
Therefore, Card Sort and SOQ Pretests beta coefficients (β) are not included in the general regression model (Field, 2005). The resulting regression model was: \[ \Delta \text{ADT} = \beta_0 + (.305 \times \text{Section}) + (.306 \times \text{ROT Pretest}) - 3.038 \] as seen in Table 4-5.

Table 4-5: Regression coefficients for ROT Pretest and Section.

<table>
<thead>
<tr>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>B</strong></td>
<td><strong>Std. Error</strong></td>
</tr>
<tr>
<td>(Constant)</td>
<td>-3.038</td>
</tr>
<tr>
<td>ROT Posttest</td>
<td>.180</td>
</tr>
<tr>
<td>Section</td>
<td>1.573</td>
</tr>
</tbody>
</table>

*Total N= 77*

*Dependent variable: \( \Delta \text{ADT} \)*

*Excluded variables: SOQ Pretest, Card Sort Pretest*

Since ROT Pretest scores demonstrated a significant influence on astronomical comprehension gain scores (\( \Delta \text{ADT} \)), statistical tests were employed to analyze any spatial aptitude development which may have occurred as a result of the astronomy unit. In other words, was any development of spatial skill found as a result of the astronomy curricula and was there an effect on ADT Posttest scores? To explore whether significant differences were found between ROT Pretest and Posttest scores for both groups, a gain variable (\( \Delta \text{ROT} \)) was computed. A two-sample independent \( t \) test was computed and results were not found to be significant (\( t(66) = -.567, p > .05 \)). Levene’s test indicated equal variances (\( F(1,66) = .402, p > .05 \)) between the two sections. The null hypothesis could not be rejected and it was concluded that there was no significant difference between ROT Pretest and Posttest scores, suggesting no evidence of spatial aptitude development as a result of the astronomy curricula. Therefore, spatial skill development did not influence ADT Posttest scores.
4-6.1 Missing values

Due to the nature of data collection for this study, some observations were not available for statistical analyses. Therefore, missing observations were replaced by the mean of the distribution for ROT, SOQ, and ADT variables as the total numbers of absent data points were below the acceptable 15 percent (George & Mallory, 2007) for each measure respectively. Missing values associated with Card Sort Activity was analyzed using pair-wise deletion of missing cases. These conscience decisions were made in order to protect the maximum number of cases for analyses while staying within the limits of ethical research (George & Mallory, 2007).

4-7. Discussion and conclusions

Results indicated a moderately correlated relationship between perception of scale and astronomical comprehension which was consistent with Tretter et al.’s (2006) findings about the importance of scale when learning and understanding science. In addition, results indicated a highly correlated relationship between spatial aptitude and astronomical comprehension which reaffirmed Rudmann’s (2002) claims about the importance of spatiality when learning astronomy. The present study also found a highly correlated relationship between scale perception and spatial aptitude which suggested that these two cognitive skill sets are interconnected and together, may serve as necessary cognitive frameworks in which to think about and organize astronomical concepts. This study suggests preservice elementary teachers’ who possess better perceptions of scale and spatial aptitudes may more accurately learn basic astronomical concepts.

The highly correlated relationship between both SOQ and Card Sort pretest assessments showed consistent measures of scale perception yet; there are fundamental
differences between the two measures. The SOQ was designed to capture participants’ ideas about scale using a linear range of orders of magnitude. Therefore, although relative rank could be used as part of selection criteria, the ranks were based on pre-determined scale ranges. In contrast, the Card Sort Activity had non-linear scale ranges without the use of metrics and the sorting criteria’s was entirely open-ended. Results on the SOQ may be indicative of using metrics to influence selection of size range in terms of ratios of magnitude. The use of both relative ranking and ratios of metrics may correlate to success on the Card Sort Activity, by assigning arbitrary values (or metrics) to card sort piles. This was evident as participants sorted cards into various piles and most often grouped all cards that were considered ‘near Earth objects’ into one pile. In this case, the Earth was used as a central point in which to relate various distances into Space. Again, although exact metrics were not known, some card descriptions were clearly categorized as proximal to Earth.

The next discrete group of cards was typically those associated with planetary distances followed by those associated with celestial objects beyond the limits of the Solar System. Most participants indicated their unfamiliarity of the metrics at these scales. By ordering the piles in which they did, the participants did indicate some scheme of size description when they indicated that cards within the extragalactic group were larger than those of the planetary and Earth-centric group. Trend (2001) found elementary teachers were more comfortable identifying geologic events using a relative ranking system which deleted the absolute metrics associated with each event. His results indicated three discrete clusters associated with Deep Time; “extremely ancient; moderately ancient; and less ancient” (p. 207). The descriptions of scaled geologic time
are analogous to astronomical distances. Participants in the present study sorted the astronomical cards into piles (although some deviation existed) using similar sorting criteria and were summarized as; continental-pile, Earth-based pile, Solar System pile, and Universe pile. Interestingly, although similar criteria were described for discrete piles, differences in card designation within each pile were quite varied. Therefore, differences existed in beliefs of fundamental astronomical dimensions, yet most employed similar sorting schemas. This was especially evident when participants overwhelmingly indicated the Space shuttle routinely orbited beyond the orbit of the Moon (and other inner-planets) which indicated a miscategorization of spatial orientations and scaled distances of the Earth’s celestial neighbors.

The use of common language supported the idea that the description of various celestial objects in terms of other celestial objects reinforced Tretter’s et al. (2006) contexts of scale. For example, one participant described the distances to the planets as such: "Cpost24: The distance from Earth to Jupiter is far, but the distance from the Earth to Pluto is really far." [See Chapter 3 for more detail on interview descriptions and coding.] The use of relative scales described by common language seemed to be the most popular cognitive strategy for providing a rationale for sorting cards associated with extreme cosmic scales. This cognitive strategy is again consistent with Trend’s (2001) work where participants used everyday language to designate geological history. In either case, exact metrics were non-essential for sorting. Although actual distances were unknown, conceptual reference points were mentally generated which inherently employed some scale schema to organize the astronomical cards into discrete piles in
specific order from smallest to largest. The application of discrete scaled distances across
the voids of Space may have been confounded by spatial orientations of celestial objects.

Results from interviews indicated that cards associated with Earth-related
descriptions were thought of using Earth as a reference point whereas cards with
considerably larger distances generated a mental picture to ‘imagine’ the distances with
respect to other cards. Therefore, the cognitive strategy to organize large astronomical
card descriptions utilized a route tour (Levelt, 1982) while Earth-centered card
organization seemed to employ a gaze tour (Ehrich & Kosters, 1983). These two
cognitive strategies may be logical approaches in which to think about the vastness of
Space.

4.8 Implications of study to teacher education

The study of astronomy is inherently associated with exotic scales and spatial
orientations and may therefore pose as a barrier to learning. The interviews reinforced the
issue of conceptually difficult aspects of learning about Space (Skamp, 1998) and
therefore underscored the objectives for this research study. The two most commonly
associated challenges to learning about Space were the unfamiliar distances and spatial
orientations of celestial objects. Yet, this study showed:

(1) Those with a more developed sense of scale perception and spatial aptitude
demonstrated a higher learning gain of accurate concepts of basic astronomy; a
finding which may strongly influence the manner in which to model astronomical
curriculum and instruction.

(2) The skill sets of spatial aptitude and scale perception are highly correlated and
proved to be essential when organizing and assimilating astronomical
information.
(3) The skills sets of spatial aptitude and scale perception serve as prerequisites to learning astronomy rather than co requisites. The choice to sample preservice teachers was quite deliberate. Based on the numerous studies which indicated preservice (Ashcroft & Courson, 2003; Trundle, Atwood, & Christopher, 2002) and in-service (Percy, 1998; Mant, 1995) teacher misconceptions of astronomical knowledge, considerable research needs to be conducted which may help identify pedagogical models in which to more effectively teach and learn astronomy. The significance of correcting preservice elementary teachers’ misconceptions wasunderscored by this study since teachers cannot help students understand astronomical phenomena if they too, do not understand (Skamp, 1998). Furthermore, teachers possessing misconceptions about science [astronomy] will miss the opportunity to identify and correct the misunderstandings of their students (Yip, 2004). As a result, students may actively reinterpret classroom instruction in support of their preexisting conceptions rather than abandoning them for more scientifically accepted explanations (Wandersee, Mintzes, & Novak, 1994; Driver & Easley, 1978).

This study identified two interconnected cognitive skill sets which effectively correlate to higher astronomy achievements: spatial aptitude and scale perception. The present study intended to analyze gains in astronomy comprehension given the developmental stage of scale perception and spatial aptitude. However, this study did not indicate any development of these two cognitive skills as a result of the astronomy curricula; which were in contrast to previous research (Black, 2006; Tretter et al., 2006; Rudmann, 2002; Orion et al., 1997).

This study only looked at the cognitive skills sets of scale perception and spatial aptitude on preservice teachers’ understanding of basic astronomical concepts as a group
and did not explore individual development. Future research may provide insight into how an astronomy curriculum may shape individual perception of scale and spatial aptitude; or augment performance on astronomy comprehension assessments. The researcher therefore invites other researchers to collaborate and expand this study to other settings.
CHAPTER 5

Twinkle Twinkle Little Star, How I Wonder *Where* You Are! A Lesson Plan Using 3-Dimensional Model to Learn about the Relative Scaled Distances of Stars from an Earth-based Observation

Title Page

Manuscript title: Twinkle twinkle little star, how I wonder *where* you are! A lesson plan using 3-dimensional models to learn about the relative scaled distances of stars from an Earth-based observation.

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Twinkle, twinkle little star, how I wonder where you are! A lesson plan using 3D models to learn about the relative scaled distance of stars from an Earth-based observation.

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Manuscript written for submission to The Science Teacher

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Abstract

One of the greatest barriers to learning accurate astronomy is the enormous scales associated with cosmic information. Research suggests that our brains simply do not do well with extreme numbers. Therefore, in order to facilitate conceptual understanding a 3-dimensional model may be used in lieu of unfamiliar metrics in order to learn about stellar distances. The stars of the constellation Orion the Hunter are used as a sample of diverse stars in which to develop a student-centered strategy to turn real-world stellar data into a practical classroom experience. Science and mathematical concepts such as scaling, ratios, and measurement are incorporated as well as the unfamiliar light-year. This hands-on approach to learning about star distances may help students create a better mental perception of the Space environment which may facilitate more accurate understanding of basic astronomical comprehension. Historical and background information is given as well as across-curriculum strategies for inter-disciplinary experiences. Safety concerns are addressed throughout the article.

Keywords High school astronomy; astronomical scale- cosmic dimensions; inquiry; in-service teacher; physics education; 3-dimensional modeling; interdisciplinary studies.

One of the largest challenges of teaching astronomy is bringing the infinite scale of the Universe into the four walls of a classroom. However, concepts of astronomy are often the most interesting to students. This article focuses an alternative method for learning about stars by exploring visible characteristics of the constellation Orion the Hunter and applying these observations to an inquiry-based modeling project. By the end of this lesson, high school grade students will be able to gain a better understanding of:

- Stars by using a hands-on project in order to see variance in stellar distances.
- Methods and interpretations of scaled astronomical distances.
- Problems with Earth-based Space exploration.
The impact of advanced technology on modern Space exploration.

When we gaze into the cosmos, our perspective from Earth may offer misleading interpretations of celestial objects. Stars may appear to be similar points of light in the night sky. Studies of Space using high-powered telescopes have indicated this is not true. Figure 1 depicts several stars of the constellation Orion the Hunter which appear brighter than those stars which comprise the dotted stellar background. The seemingly two-dimensional plane in which these points of light in the night sky reside may not lead to accurate conceptions about stellar distances. Table 5-1 outlines common children’s misconceptions about stars (AIP, 1998) and the appropriate astronomy education Benchmark (AAAS, 2008).

Table 5-1: Common misconceptions about stars and astronomy education Benchmarks.

<table>
<thead>
<tr>
<th>Common Misconceptions of Stars†</th>
<th>Benchmarks of astronomy education‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>All the stars in a constellation are near each other.</td>
<td>The stars differ from each other in size, temperature, and age</td>
</tr>
<tr>
<td>All the stars are the same distance galaxy is very crowded.</td>
<td>Unlike the sun, most stars are in systems of two or more from the Earth. The stars orbiting around one another.</td>
</tr>
<tr>
<td>All stars are the same size and are evenly distributed throughout the Universe.</td>
<td>Stars condensed by gravity out of clouds of molecules of the lightest elements until nuclear fusion of the light elements turn into heavier ones.</td>
</tr>
<tr>
<td>The brightness of a star depends only its distance from the Earth.</td>
<td>Fusion released great amounts of energy over millions of years.</td>
</tr>
<tr>
<td>Stars are evenly distributed throughout the Universe. constellations form patterns clearly resembling people, animals or objects.</td>
<td>Eventually, some stars exploded, producing clouds containing heavy elements from which other stars and planets orbiting them could later The condense. The process on of star formation and destruction continues.</td>
</tr>
<tr>
<td>Increasingly sophisticated technology is used to learn the galaxy.</td>
<td></td>
</tr>
</tbody>
</table>

Source: AIP (1998)† and AAAS (2008)‡
Many of the misconceptions listed are associated with an Earth-based perspective (beneath our atmosphere) looking out toward a dark two-dimensional ‘ceiling’. This ‘ceiling effect’ may deceive students’ interpretation of inter-stellar distances as they gaze across the vast distance into outer Space (Black, 2005). In addition, the swirling gasses of Earth’s atmosphere may fool the casual observer by blurring a star’s individual signatures, or star light. Only through expert observation and inference can accurate distances to the stars be discovered. However, the use and manipulation of experts’ discoveries can be implemented into the classroom in an inquiry-based lesson which effectively models experts’ attempts to map the starry skies.

5-2. A lesson plan to study the relative distances of stars in the constellation Orion the Hunter

Grade: High school level
Time: One block schedule or two 55 minute periods
Math Ability: Basic conversions and scale manipulation, accurate measurement skill, basic geometry.

5-3. The pre-assessment (5 minutes)

The lesson begins with a pre-assessment where paired students are asked to discuss and write down how distances to the stars are determined. The application of parallax theory in which to calculate stellar distances and the derivation of astronomical units of measure which described these distances were concisely addressed in Murphy and Bell’s (2005) article ‘How far are the stars?’ in *The Science Teacher* 72(2), 38-43. When students are finished writing, guided questioning may begin by looking at relative scales among more familiar distances such as:

- The stars are too far to be measured.
- I know you can measure them but I have no idea.
- They are all just really far away.
- Stars [other than our Sun] reside within our galaxy.
- You use star light.
as distances located around the classroom, within the town, across the country, and into Space. In other words, students may begin by describing distance using common language rather than absolute metrics to describe relative position. For example, the distance from the teacher’s desk to the wall is twice the distance from the teacher’s desk to the flag. Students should write the answers down in their science journal (or notebook) as their thoughts will be revisited later in the lesson. The use of common language will be useful when comparing star distances as the conceptualization of astronomical distances prove to be difficult for the human mind to comprehend.

5-4. The optical illusion

The direct observation of the stars from the Earth’s surface is directly confounded by the atmosphere. In order to illustrate this point, we turn to the nearest celestial neighbor for clarification as the Moon’s proximity to Earth (and familiarity) makes it much easier to observe and discuss. Two images depicting various Moon diameters (Figure 5-2) are shown in order to facilitate discussion about apparent sizes and distances of objects in the sky. Such questions to facilitate discussion are ‘Why do objects in the sky look the way they do?’ ‘Do objects in the sky always look the same? Why or why not?’ ‘Can you compare different objects in the sky? How?’ ‘What are some similarities and differences between objects you see in the sky?’ ‘Can we always see objects in the sky? Why or why not?’ This activity offers the students an opportunity to understand why celestial objects are sometimes not as they may appear from our Earth-based vantage point.

Common student responses:
- Planets look like stars in the sky.
- Clouds may block our view of stars.
- It [celestial object view] depends on the where the Sun is.
- The Sun is the brightest object in the sky.
- Some stars are brighter than others.
5-5. **Challenge activity (10 minutes)**

The challenge activity now applies the difficulties of sky observation to the stars; a task that was a bit harder to conceptualize due to the smaller stellar diameters and larger stellar distances. In pairs, the participants were shown a high quality image of the constellation Orion the Hunter via computer projection (or overhead projector) as shown in Figure 5-3 (Figure shown should not include star distance labels.) The nine major stars (including the Orion Nebula) were labeled with letters A-I. The students were then asked to rank the stars in order from the closest to furthest from Earth and establish criteria for their selections. A guided discussion created a punch list of class ideas about star distances based on the selection criteria each group developed.

5-6. **The 3-dimensional model (30 minutes)**

5-6.1. **Materials**

The 3-dimensional model representing relative distances of stars within the constellation Orion utilize wooden skewers (sharpened on one end) and a piece of ½ inch foam-board. The use of supermarket stock wooden skewers used for daily shish-kebabs work the best as they are inexpensive and easily manipulated. Sharp scissors or shears capable of cutting narrow circumference wooden skewers are necessary to ensure safe manipulation of skewer cutting. Traditional metric rulers are used to measure wooden skewers to desired length. A copy of the constellation Orion will be cut out, glued to the foam board and used as a guide in which to insert measured skewer lengths. Finally, white paint (or Whiteout) may be used as a coloring mechanism to increase contrast of common student criteria included:

- *Star B is closest because it is the brightest.*
- *Star C is closest since it has the largest diameter.*
- *The stars of Orion’s belt are all the same distance away since they are in a line and the same size/brightness.*
- *Star J is furthest because it is the dimmest/smallest.*
wooden skewer edges as well as seal the cut ends of the skewers for safer handling. Safety note: the cutting of wooden skewers may be difficult for some students and should therefore be done with safety in mind. For students with adaptations, partners may provide aid in the act of cutting and measuring. Protective goggles will shield students’ eyes from any wooden splinter that may be ejected during the act of cutting. Also, wooden skewers are sharpened on one end in order to make insertion into the foam-board less problematic.

5-6.2. Selecting a scale model of stellar distances

The capacity for students to obtain directly measured data of stellar distances may be beyond the means of a typical science classroom. Therefore, estimated star distances in light-years should be provided by a credible source such as the Sloan Digital Sky Survey at the University of Chicago. A brief review of the light-year can be found in Robertson’s (2006) article ‘Science 101: Why is a light-year a unit of distance rather than a unit of time?’ in Science and Children 44(2), 17-19.

However, students may use, manipulate, and contemplate star distance data points in a meaningful manner in which to compare stellar distances with respect to each other. For example, a student may choose to represent 1 centimeter to approximate 200 light years. This ratio may be applied to the Orion Nebula by cutting a wooden to skewer to measure 8 centimeters (1cm/200ly = X cm/1600ly = 8 cm) since the approximate distance to the Orion Nebula is 1600 light years. Using this ratio, the distance from Earth to the enormous Red Giant Betelguese would measure to approximately a 2.1 centimeter piece of cut wooden skewer. Using this student defined scale example, the cut wooden skewer used to represent the approximate distance from Earth to the Red Giant
Betelguese would yield a cut wooden skewer piece measuring approximately four times the length of a cut wooden skewer length used to represent the distance from Earth to the Orion Nebula. (A listing of sample scaled stellar distances can be found in Table 5-2). Note: measuring the wooden skewer should begin just above the tapered section of the skewer to allow for the skewer to be inserted into the foam-board. The scaling theme used in this example would then convey relative stellar distances without asking the student to think in terms of exotic metrics, such as those described by light-years.

5-6.3. Putting the pieces together

Once students have a set selected a defined scale, the wooden skewers should then be cut to scaled measured lengths for each respective star in order to assemble the 3-dimensional model of the constellation Orion. Students should glue down a print out of the constellation of Orion (Figure 5-4) onto a piece of appropriately sized foam board. Each scaled piece of wooden skewer should now be inserted into the appropriate star by inserting the tapered end of the skewer into the foam board allowing the skewer to protrude vertically into the surrounding air. This process should be repeated for all nine celestial objects. Once all skewers are in place, use white paint (or white-out) to paint the tops of the skewers for added contrast. The result will be a three-dimensional scaled model of the relative distances to most of the stars in the constellation Orion.

5-6.4. Using the 3-dimensional model

The model can now be used to represent an Earth-based perspective in the relative stellar distance of the constellation Orion. In order to do so, the model should be held at eye-level, horizontal to the floor, where students can observe the relative scaled skewer lengths of star distances with respect to each other. Careful observations may be directed
toward to the relative distances between the three stars which comprise Orion’s famous belt. In this example, the longer the skewer length the further away from Earth’s surface, which may be quite a contrast to the seemingly equidistant positions of the three stars on Orion’s belt.

Another perspective allows the students to mimic a real life observation by inverting the model to an overhead position. The model should be oriented so the vertical skewers are pointing down directly at the observers eyes. From this vantage point, the 3-dimensional skewers appear to be depthless, similar to the students’ familiar Earth-based perspective (Figure 5-5). The model can be rotated along three-axes to offer various perspectives of relative star positions. Note: the model is not intended to represent stellar distances from the eyeball to the cut end of the skewer. This may create an inaccurate representation of the models intended use by asserting that longer skewers represent closer positions to Earth. Sample student work can be found in Figure 5-5 and 5-6.

5-7. Wrap-up/Extension (15 minutes)

The scaled 3-dimensional model concept can be used to represent variety of astronomical concepts which can be applied to the scaled diameters, magnitudes, and temperatures of numerous celestial objects. Extending scaled stellar distance to diameters of Red Giants versus Type II stars, intra-Solar System planetary orbits, and gravitational fields, may be effective in conceptualizing abstract astronomical concepts. Encourage students to think about where additional scaled models may help conceptualize astronomic phenomena and what frequent problems are incurred by ground-based Space exploration. Promote the use of common language to bolster the development of astronomic theories into everyday vernacular. Finally, encourage students to bring the 3-
dimensional scaled models home to family member to share the complex descriptions of extreme metrics using simple 3-dimensional models and common language.

5-8. Assessment

To check for understanding, have students revisit the criteria used before the lesson to estimate stellar distances and contrast decision-making between class members. Furthermore, use the model as a basis to create a news report which highlights the use of scaled distances to the stars of Orion. The news report will prompt students to make use of common language while addressing the public. Check for correct applications of scaled metrics and applications of cosmic distances.

5-9. Planning across curriculum

Cultures around the world have different explanations of the constellation Orion. Encourage students to include numerous historical interpretations (Rau, 2006) of the legend constellation from ancient Greek to modern day Africa. Orion has been featured in numerous pop-culture events such as movies and television programs (see Stargate, Men in Black, etc) and may offer a valuable connection between disciplines. Overall, Orion has a rich cultural representation that may provide a natural bridge between astronomy and world cultures.

5-10. Lesson motivation

The development and application of student-defined relative scales in which to conceptualize astronomical phenomena associated with extreme scales are shown to be more effective methods of information organization when used in conjunction with common language. Refer to Tretter and Jones’s (2003) article ‘A Sense of Scale: Studying how scale affects systems and organisms’ in *The Science Teacher, 70*(1), 22-25
for a review of scaling applications. Students may gain a better understanding of the relative distances of stars allowing them to turn a vast two-dimensional mosaic of the constellation Orion into a rotatable 3-dimensional model of scaled stellar distances. Many common astronomical misconceptions are closely associated with the vast distances and spatial relationships of the stars. I encourage you to explore the mysterious cosmos in your classroom, and let the natural curiosity of your students foster a meaningful learning experience in astronomy. Look up!

<table>
<thead>
<tr>
<th>National Science Education Standards: 9-12 Earth and Space Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science Content Standards D:</td>
</tr>
<tr>
<td>Origin and evolution of the Earth system</td>
</tr>
<tr>
<td>Origin and evolution of the Universe</td>
</tr>
<tr>
<td>Science Content Standard E:</td>
</tr>
<tr>
<td>Understandings about science and technology</td>
</tr>
</tbody>
</table>

.Side bar

*Why constellation Orion?*

The choice to use the constellation Orion the Hunter was quite deliberate. Orion is a very well known constellation observable from anywhere in the world due to its low position on the celestial equator. At the very least Orion’s belt which is comprised of three bright stars in a seemingly straight line (from Earth perspective) are often identifiable by a novice observer. In addition, Orion contains a various types of celestial objects. The constellation contains stars of various sizes and magnitudes by classification. For example, Betelguese is a considered a red giant (approximately 800 solar diameters) and Rigel is a blue giant (approximately 62 solar diameters). The constellation also contains
the Orion Nebula, the remnants of an exploded star approximately 30 light years across. However, residing approximately 1600 light years away from Earth, light from the Nebula is observed by the unaided eye as a single point of reddish light. Orion’s belt also offers some interpretation. Although these three stars seem close to each other and are similar in apparent brightness, they actually reside at drastically different distances from Earth. How can they be the same apparent magnitude? Finally, the choice to use Orion as the constellation of choice is due the constellation’s place in pop culture. Numerous movies, NASA missions and Space craft make use of the famous constellation’s name. As we look into the stars at night, quite often you can hear people say, “Oh, I see Orion’s belt!”
Figure 5-1: Constellation Orion the Hunter.

Photo credit: Akira Fujii

Figure 5-2: Two sample photos used for student comparison.

Photo credit: Marshall Space Flight Center/NASA

Photo credit: Connetta Jean

Figure 5-3: Sample slide with star names, distances, and guiding questions.

Credit: Charles Fidler
Table 5-2: Sample student generated data for star distances and conversions.

<table>
<thead>
<tr>
<th>Star</th>
<th>Distance away from Earth in light years</th>
<th>Converted cm length of skewer</th>
<th>Plus one centimeter for foam board</th>
</tr>
</thead>
<tbody>
<tr>
<td>Betelguese</td>
<td>427</td>
<td>2.1</td>
<td>3.1</td>
</tr>
<tr>
<td>Hatsya</td>
<td>1300</td>
<td>6.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Bellatrix</td>
<td>243</td>
<td>1.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Alnитak</td>
<td>815</td>
<td>4.1</td>
<td>5.1</td>
</tr>
<tr>
<td>Alnilam</td>
<td>1350</td>
<td>6.8</td>
<td>7.8</td>
</tr>
<tr>
<td>Mintaka</td>
<td>916</td>
<td>4.6</td>
<td>5.6</td>
</tr>
<tr>
<td>Orion Nebula</td>
<td>1600</td>
<td>8.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Saiph</td>
<td>720</td>
<td>3.6</td>
<td>4.6</td>
</tr>
<tr>
<td>Rigel</td>
<td>773</td>
<td>3.9</td>
<td>4.9</td>
</tr>
</tbody>
</table>

Source: Sloan Digital Sky Survey, University of Chicago.
Figure 5-4: 4 x 5 inch constellation Orion the Hunter cut out.

Photo credit: Akira Fujii
CHAPTER 6

Conclusions

The exploration of Space has advanced by leaps and bounds since ancient civilizations first began systematic observation of the sky. Technology and knowledge generation has progressed steadily over time which has made the distribution of electronic Space information readily accessible. However, interpretation and mental conceptualization of Space information may be susceptible to misunderstanding based on the unknown dimensions associated with astronomy and naïve-theories generated from personal experiences. The repairing of misunderstood astronomical information among preservice elementary teachers served as a fundamental underpinning for the current research study.

The present research study was designed to really explore how preservice elementary teachers think and learn about astronomy. Given the vast dimensions and spatiality of the cosmos, a logical starting point was to understand how preservice teachers conceptualize dimensions of Space related phenomena. Results from this section of research suggested numerous misconceptions directly associated with scaled dimensions of Space such as the extent of manned Space exploration, the composition and expanse of the Solar System and stars, and the conceptualization of a light-year. Results also indicated that the perception of cosmic dimensions may change which may influence the conceptualization of more accurate astronomical information. However, results did indicate that despite the change which may existed, a fundamental barrier to learning about Space are the enormous metrics associated with astronomical dimensions. The light-year is an example of an unfamiliar distance that was quite problematic for
preservice elementary teachers. Although most of us, including preservice elementary teachers, are unfamiliar with a light-year this study showed that even cosmic dimensions can thought of in comparative dimensions to help imagine orientations of celestial objects. This finding suggests that there are certain strategies that are more effective for thinking about the huge dimensions of Space and that the initial thoughts of an inconceivable expanse can actually be thought of in a useful manner.

An example which provided an application of these finding was included in this dissertation as an inquiry based lesson. The lesson is designed to allow for astronomy learners to analyze the orientation of stars in the constellation Orion the Hunter. The lesson calls for participants to use mathematical skills to develop a self-derived scaling strategy for comparing stellar distances using basic materials. The activity called for participants to use known estimated distances to Orion’s stars and scaled them to relative distances. In this activity, the obscure distance of a light-year was masked by the representation of the three-dimensional model. Participants could now compare the distances noting if stars were one, two, three, or more times as far away from each other and the Earth’s surface. The use of relative comparison facilitated the participants to conceptualize unfamiliar cosmic dimensions by staying clear of exact known metrics (Tretter et al, 2006).

The next part of the present research study looked to explore how specific skill set play a role when learning astronomical information. In other words, what cognitive skills, if any, facilitate the re-organization of cosmic dimensions after when learning astronomy? Previous research indicated success in science when concepts of scaling (Tretter et al, 2006) and spatial-aptitude (Black, 2005; Rudman, 2002; Bodner & Guay,
were applied among various science disciplines. Due to the known vast dimensions of Space, an in-depth look into how scale and spatial concepts played a role when learning astronomy were analyzed by quantitative analyses. Validated measures designed to assess pre and post preservice teachers spatial-aptitude and scale perception were administered in order to obtain useful data. In addition, the two sections were administered two different astronomy curricula in order to compare how scale and spatially rich lessons affected astronomy comprehension when compared to a more traditional Space course.

Results indicated that preservice teachers with a more developed sense of scale perception showed higher scores in spatial-aptitude, which correlated to higher astronomic comprehension scores. These results confirm previous research and are specifically focused on astronomy. The fact that those preservice teachers with a more advanced perception of scale and spatiality showed higher scores on astronomy comprehension helps to inform aspects of astronomy education which may promote more effective curriculum design and pedagogical practices. These results were found among both groups of the present research study.

However, the comparison between groups in this study was designed to explore how different activities may shape the outcome of astronomical comprehension. The treatment group engaged an astronomy curriculum explicitly laden in activities associated with scale and spatiality. The comparison group was exposed to a unit where scales and spatial orientations were pedagogical approaches in a traditional based curriculum. Results found that those in the treatment group showed overall higher astronomic comprehension scores than the comparison group. This finding showed how prominent
concepts of scale and spatiality may be among the pursuit of astronomy education. In short, all aspects of this dissertation show how both cognitive skill sets of scale perception and spatial-aptitude play a crucial role when learning aspects of astronomy.

6-1. Limitations

This study was designed to deliver high quality astronomy education to both groups associated with the research study. However, due to the nature in which the astronomy unit was implemented, only four to five weeks was dedicated to the entire astronomy unit. The short nature of the research may have limited some of the findings of this study. Therefore, a longer study may find more in-depth results which may provide more examples of how preservice elementary teachers conceptualize cosmic dimensions. In addition, a longer study may look to analyze any development of scale perception or spatial aptitude as a result of an extended astronomy education experience. Future research may be conducted in this area to further advance the field of astronomy education.

Some of the data collection measures and astronomy unit instruction were conducted by colleagues to facilitate a timely manner of data collection and effective daily classroom operations. Although explicit instructions were given to assistants, the use of third party data collectors always carries with it the risk of erroneous data collection. Therefore, a limitation found in this study was the use of assistants for primary data collection. Errors were minimized by careful supervision of measure administration and astronomy instruction, yet errors still occurred. This could have been mitigated by a longer time period for the research design.
The physical classroom environment and sample sizes were one not conducive to science instruction as a traditional lecture hall setting was in place for larger student audiences. Therefore the use of assistants, multiple rooms, and the lack of technology were factors which contributed to a more hectic daily classroom schedule of events. However, these resources were what were available for use during instruction and therefore careful attention and pre-planning was essential to the integrity of this study. The detailed descriptions of daily classroom activities can be found in Chapter 2.

Finally, participant apathy combined with user-performance of study measures may have been a limitation to the highest quality data collection available. This study was measure intensive and asked participants to fill out many pre and post measures. Participants often expressed some resentment for having to fill out another ‘questionnaire’ when “Tpost02: These don’t even count for our grade!” Therefore, the measures were administered in the most non-obtrusive manner possible, except for the card sort activity which required participants to schedule two outside of class meetings. This proved to be problematic. Careful attendance was recorded and a system of email reminders and flexibility of schedules catered to participants’ diverse schedules. Since this was a pre-post intervention design, absences caused erroneous data, which was handled by careful monitoring and sensitive data cleansing.

Although these limitations existed, the participants’ well-being was held with the utmost importance. This is partially due to maintain the integrity of the dissertation study as well as the identification of the participants’ as future elementary teachers.

Preservice teachers are charged with the responsibility to teach children about numerous subjects, including astronomy. However, misconceptions of basic astronomy
concepts are found among preservice and in-service teachers. In order to help prepare future elementary teachers to teach children astronomy, mechanisms must be in place which effectively facilitates the organization of accurate astronomic information. The present study highlighted numerous finding which did, in fact, augment the re-organization of astronomy concepts, clarifying misconceptions before the preservice teacher entered the elementary classroom. Given the limited time of formalized science content available in many elementary teacher preparation programs, careful attention needs to be placed on the quality of astronomy content found within science courses designed for preservice elementary teachers.

As mentioned in the introduction of this study, there are many reasons why astronomy may not be taught in an elementary classroom; most notably, the elementary teacher’s lack of astronomy understanding (Percy, 1998). In order to break the vicious cycle of teacher-student misconception generation, the elementary needs to have a sound understanding of accurate astronomical science.

The field of elementary science education reform calls for research on preservice elementary teacher preparation (NAP, 2007) in order to promote the future of quality elementary teachers. The implications of this charge reach far beyond the walls of the classroom and ultimately reach into all facets of society. The economic future depends on future citizens to enter into science and engineering fields such as technology, energy and transportation, Space exploration, food sciences, and medicine. The increase in accurate astronomic information among preservice teachers today may enhance the national pool of scientists and engineers tomorrow.
7. APPENDICES

Appendix A: Astronomy Education in the K-8 National Standards

Despite the de-emphasis of astronomy education, the Benchmarks for Science Literacy (AAAS, 2008), the National Science Educations Standards (NSTA, 2003), and the National Science Education Standards (NRC, 2003) highlighted both the importance of astronomy education and outlined what students and teachers ought to know by then end of appropriate grade levels. The reason for including the middle school grades (5-8) is that preservice teachers in this study will be certified grades 1-6. Across grade level or subject area teaching has become more common place especially in areas with critical teacher levels. Due to the national teacher shortage often rural and urban school districts are forced to employ new teachers to teach grades levels and subjects beyond their expertise (Duggan-Shwartzback, Prince, Redfield, Morris, Cahampe-Hammer, 2003).
### NSTA Elementary/Middle Generalists

<table>
<thead>
<tr>
<th>Properties of light</th>
<th>NSTA Elementary/Middle Science specialists</th>
<th>Related Astronomical Benchmarks 1-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>There are more stars in the sky than anyone can easily count, but they are not scattered evenly, and they are not all the same in brightness or color*</td>
<td>Structures of objects and systems in Space</td>
<td>Planets change their positions against the background of stars†</td>
</tr>
</tbody>
</table>

### NSTA Elementary/Middle Science specialists

<table>
<thead>
<tr>
<th>Related Astronomical Benchmarks 1-8</th>
<th>Related Astronomical Benchmarks 1-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structures of objects and systems in Space</td>
<td>Planets change their positions against the background of stars†</td>
</tr>
</tbody>
</table>

† Stars are like the Sun, some being smaller and some larger, but so far away that they look like points of light†

‡ The Sun is many thousands of times closer to the Earth than any other star. Light from the Sun takes a few minutes to reach the Earth, but light from the next nearest star takes a few years to arrive†

### Natural objects in the sky and why they change in position and appearance

<table>
<thead>
<tr>
<th>The Sun can be seen only in the daytime, but the Moon can be seen sometimes at night and sometimes during the day*</th>
<th>Earth’s structure, evolution, history, and place in the Solar System</th>
<th>The Earth is one of several planets that orbit the Sun, and the Moon orbits around the Earth†</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Sun, Moon, and stars all appear to move slowly across the sky*</td>
<td>The Earth is one of several planets that orbit the Sun, and the Moon orbits around the Earth†</td>
<td>Like all planets and stars, the Earth is approximately spherical in shape. The rotation of the Earth on its axis every 24 hours produces the night-and-day cycle. To people on Earth, this turning of the planet makes it seem as though the Sun, Moon, planets, and stars are orbiting the Earth once a day†</td>
</tr>
<tr>
<td>The Moon looks a little different every day, but looks the same again about every four weeks*</td>
<td>We live on a relatively small planet, the third from the Sun in the only system of planets definitely known to exist!</td>
<td>We live on a relatively small planet, the third from the Sun in the only system of planets definitely known to exist!</td>
</tr>
<tr>
<td>Because the Earth turns daily on an axis that is tilted relative to the plane of the Earth's yearly orbit around the Sun, Sunlight falls more intensely on different parts of the Earth during the year. The difference in heating of the Earth's surface produces the planet's seasons and weather patterns‡</td>
<td>The Sun is a medium-sized star located near the edge of a disk-shaped galaxy of stars. The Universe contains many billions of galaxies, and each galaxy contains many billions of stars. To the naked eye, even the closest of these galaxies is no more than a dim, fuzzy spot‡</td>
<td>The Sun is a medium-sized star located near the edge of a disk-shaped galaxy of stars. The Universe contains many billions of galaxies, and each galaxy contains many billions of stars. To the naked eye, even the closest of these galaxies is no more than a dim, fuzzy spot‡</td>
</tr>
<tr>
<td>The Moon's orbit around the Earth once in about 28 days changes what part of the Moon is lighted by the Sun and how much of that part can be seen from the Earth-the phases of the Moon‡</td>
<td>Large numbers of chunks of rock orbit the Sun. Some of</td>
<td>Large numbers of chunks of rock orbit the Sun. Some of</td>
</tr>
</tbody>
</table>
those that the Earth meets in its yearly orbit around the Sun glow and disintegrate from friction as they plunge through the atmosphere and sometimes impact the ground.

| Causes of the seasons and seasonal changes | The patterns of stars in the sky stay the same, although they appear to move across the sky nightly, and different stars can be seen in different seasons.
| Characteristics of the atmosphere including weather and climate | The Earth is mostly rock. Three-fourths of its surface is covered by a relatively thin layer of water (some of it frozen), and the entire planet is surrounded by a relatively thin blanket of air. It is the only body in the Solar System that appears able to support life. The other planets have compositions and conditions very different from the Earth’s.

| Impact of science and technology on themselves and their community, and on personal and community health. | Telescopes magnify the appearance of some distant objects in the sky, including the Moon and the planets. The number of stars that can be seen through telescopes is dramatically greater than can be seen by the unaided eye.

---

1 End of second grade
2 End of fifth grade
3 End of eighth grade
<table>
<thead>
<tr>
<th>Scale of Objects Questionnaire (SOQ)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 1: Do you prefer large or small objects?</td>
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<tr>
<td>Question 2: How do you feel about the size of objects in your environment?</td>
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<tr>
<td>Question 3: How do you perceive the scale of objects in your daily life?</td>
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</tr>
<tr>
<td>Question 4: Do you find the scale of objects appropriate in your environment?</td>
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</tr>
<tr>
<td>Question 5: How do you think the size of objects affects your mood?</td>
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</tr>
<tr>
<td>Question 6: Do you notice the scale of objects when you are in a new environment?</td>
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</tr>
</tbody>
</table>

This is an excerpt from the Scale of Objects Questionnaire (SOQ). Please answer each question truthfully to the best of your ability. Thank you for your participation.
Appendix C: List of cards descriptions for Card Sort Activity in correct order.

1. Nucleus of an oxygen atom
2. Diameter of a hydrogen atom
3. Diameter of a water molecule
4. Length of a typical virus
5. Diameter of a red blood cell
6. Width of a piece of thread
7. Thickness of a penny
8. Length of an apple seed
9. Diameter of a quarter
10. Width of an electrical outlet cover
11. Length of a business envelop
12. Height of a typical 5 year old boy
13. Height of an NBA player
14. Length of an SUV
15. Length of a typical bedroom
16. Length of a soccer field
17. Span of the longest bridge in the world
18. Altitude the Space Shuttle orbits
19. Distance to the ISS orbit to Earth
20. East-west distance of NY
21. Distance from Boston to LA
22. Distance from Syracuse to Sydney
23. Diameter of the Earth
24. Diameter of Jupiter
25. Distance from Earth to the Moon
26. Distance of farthest manned Space exploration
27. Diameter of the Sun
28. Distance from Sun to Earth
29. Distance from Sun to Mars
30. Distance from Sun to Jupiter
31. Distance from Sun to Pluto
32. Distance from Earth to the edge of the Solar System
33. Distance of a light year
34. Distance from Earth to the nearest star (Proxima Centauri)
35. Distance from Earth to the North Star
36. Distance from Earth to the center of our galaxy
37. Distance across the Milky Way galaxy
38. Distance from Earth to the nearest galaxy
39. Distance from Earth to the farthest known galaxy
Appendix D: Sample Purdue Visualizations of Rotations Test (ROT)

Do NOT make any marks on this exam.
Mark your answers on the separate answer sheet.

DIRECTIONS

This test consists of 20 questions designed to see how well you can visualize the rotation of three-dimensional objects. An example of the type of question included in this test is shown below.

IS ROTATED TO

AS

IS ROTATED TO

A

B

C

D

E

For each question, you should:

I. Study how the object in the top line of the question is rotated.

II. Picture in your mind what the object shown in the middle line of the question looks like when rotated in exactly the same manner.

III. Select from among the five drawings (A, B, C, D, or E) given in the bottom line of the question the one that looks like the object rotated in the correct position.

What is the correct answer to the example shown above?
Appendix E: Astronomy Diagnostic Test 2.0 (ADT)

June 21, 1999
Version 2.0

Attention: Please DO NOT Write on this survey! Thank You!

Introductory Astronomy Survey

1. As seen from your current location, when will an upright flagpole cast no shadow because the Sun is directly above the flagpole?
   A. Every day at noon.
   B. Only on the first day of summer.
   C. Only on the first day of winter.
   D. On both the first days of spring and fall.
   E. Never from your current location.

2. When the Moon appears to completely cover the Sun (an eclipse), the Moon must be at which phase?
   A. Full
   B. New
   C. First quarter
   D. Last quarter
   E. At no particular phase

3. Imagine that you are building a scale model of the Earth and the Moon. You are going to use a 12-inch basketball to represent the Earth and a 3-inch tennis ball to represent the Moon. To maintain the proper distance scale, about how far from the surface of the basketball should the tennis ball be placed?
   A. 4 inches (1/3 foot)
   B. 6 inches (1/2 foot)
   C. 36 inches (3 feet)
   D. 30 feet
   E. 300 feet

4. You have two balls of equal size and smoothness, and you can ignore air resistance. One is heavy, the other much lighter. You hold one in each hand at the same height above the ground. You release them at the same time. What will happen?
   A. The heavier one will hit the ground first.
   B. They will hit the ground at the same time.
   C. The lighter one will hit the ground first.

5. How does the speed of radio waves compare to the speed of visible light?
   A. Radio waves are much slower.
   B. They both travel at the same speed.
   C. Radio waves are much faster.

6. Astronauts inside the Space Shuttle float around as it orbits the Earth because
   A. there is no gravity in space.
   B. they are falling in the same way as the Space Shuttle.
   C. they are above the Earth's atmosphere.
   D. there is less gravity inside the Space Shuttle.
   E. more than one of the above.

PLEASE TURN THE PAGE

1999 The Collaboration for Astronomy Education Research (CAER)
8. Bibliography


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