

YOUNG ELEMENTARY STUDENTS' CONCEPTUAL UNDERSTANDINGS OF
LUNAR PHASES BEFORE AND AFTER AN INQUIRY-BASED AND
TECHNOLOGY-ENHANCED INSTRUCTIONAL INTERVENTION

DISSERTATION

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ABSTRACT

This mixed methods study explored young children's understandings of targeted lunar concepts, including when the moon can be observed, observable lunar phase shapes, predictable lunar patterns, and the cause of moon phases. Twenty-one children (ages seven to nine years) from a multi-aged classroom participated in this study. Data were collected using semi-structured interviews, student drawings, and card sorting before and after an inquiry-based, technology-enhanced instructional intervention. Students' lunar calendars, written responses, field notes, and videotaped class sessions also provided data throughout the study. Data were analyzed using codes from prior lunar studies, constant comparative analysis, and nonparametric analysis. The instructional intervention included lunar data gathering, recording, and sharing, through the use of *Starry Night* planetarium software and an inquiry-based instruction on moon phases (McDermott, 1996). In a guided inquiry context children worked in groups to gather and analyze nine weeks of lunar data. Findings indicated a positive change in students' understanding of all targeted concepts. After the intervention more children understood that the moon could be observed sometimes during the day, more children drew scientific moon phase shapes, and more children drew scientific representations of the moon phase sequences. Also, more children understood the cause of moon phases.

Dedicated to my loving family

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CHAPTER 1

INTRODUCTION

This dissertation study was designed to describe, report, and interpret the responses of Primary children during a moon study project. Qualitative and quantitative data from the moon explorations were collected prior to and after children engaged with lunar data collection and analysis during an instructional intervention. To answer the research questions, the researcher integrated both qualitative and quantitative data in a single case, pre-test and posttest design. As the participant observer, I followed my own Primary classroom students, as a classroom teacher and researcher, for a period of six weeks.

The *National Science Education Standards* (National Research Council [NRC], 1996) target understanding lunar concepts as part of the scientific literacy outlined for Grades K-4. Students at these grade levels are expected to study the patterns of movement and observable shape changes in the moon. Based on the suggested standards, this study examined Primary students' ideas about observable moon phases, moon phase sequences, and patterns of sequences prior to and following collaborative explorations in lunar data collection and analysis of observational moon data. In addition to the recommended standards, students explored the cause of lunar phases using an instructional intervention designed to promote the students' conceptual understanding of this phenomenon. Analysis of the findings was based on the cognitive

and socio-cultural perspectives of learning and development within a multi-age science classroom.

This chapter describes the background of the classroom-based study, explains the educational significance of the project, and identifies the research questions that guided this project. This chapter also reviews the limitations of the study and defines key terms used in the study.

Background of the Study

Factors that contributed to the conceptualization of this investigation include trends in science education related to using inquiry and technology as pedagogical tools, educational research related to conceptual change theory in the science classroom, and socio-cultural aspects of science learning and teaching.

Educational Trends

This classroom-based study took place during a time when standards-based instruction and assessment influence how and when science learning is constructed. The *National Science Education Standards* suggest that in order for deep conceptual understanding to occur students should use inquiry to guide explorations. Students should pose questions about the natural world and investigate phenomena. According to the *National Science Education Standards* (NRC, 1996), in using inquiry

...students acquire knowledge and develop a rich understanding of concepts, principles, models, and theories. ...students will learn science in a way that reflects how science actually works (p. 214).

In addition, the standards also support student-directed inquiry and collaborative work to solve science investigations (NRC, 1996). Scientific inquiry is recognized as being a

way that may encourage students to think scientifically about everyday events (American Association for the Advancement of Science [AAAS], 1993).

Despite the call for inquiry learning as a central strategy in science education, there is very little empirical research surrounding the use of inquiry with young children in the science classroom. The present study embodied the positive aspects of children's engagement with inquiry. Students investigated lunar phenomena while using scientific inquiry skills, such as observing, posing questions, predicting, collecting data, analyzing data, communicating, and forming conclusions from the data.

Another trend in science education is the use of technology within the classroom (International Society for Technology in Education [ISTE], 2003). Technology and the use of visual representation is a way to engage students in active inquiry. Compact discs, videos, and the Internet are examples of pedagogical tools that supplement and complement science learning about concepts and events that can often be abstract or difficult to observe (Alvermann, 2005; Trundle & Bell, 2003). The *National Science Education Standards* (NRC, 1996) suggest that all students in grades K-4 should develop the ability to use and understand science through technology and technological tools that help students make better observations and measurements (p.138). While exploring with technology, students are able to connect with science by experiencing models of our world, the laws of nature, and how systems work. Students in the present study used *Starry Night* (version 5.0, Imaginova), a planetarium software program, to observe patterns and lunar events, collect and analyze data, and plan further explorations. This software program has been effectively used in other research with

pre-service elementary teachers (Trundle & Bell, 2006) and elementary students (Hobson & Trundle, 2007).

Educational research related to conceptual change theory in the science classroom was another factor that supported this study.

Conceptual Change Research

Children are not passive learners. They come to school already holding a rich, intuitive understanding of their natural world (Vosniadou & Brewer, 1992). The following quote emphasizes this point:

Since 1929, when Piaget first demonstrated that children's learning is powerfully influenced by their own preexisting conception of the world, educational researchers and practitioners have sought to understand children's notions and design curricular content to match and build on their previous understanding (Strommen 1995, p. 683).

These preexisting conceptions and ideas may or may not be aligned with scientific views (Duit & Treagust, 2003). Many of the non-scientific views, commonly called alternative conceptions, have been noted in various areas of science with most studies of students' alternative perceptions related to the physical world. For example, there have been over 116 studies reporting that students come to their science classrooms holding alternative conceptions about astronomical phenomenon (Pfundt & Duit, 1998).

Educational research reflects the growing interest in students' science conceptual frameworks and how alternative conceptions can be used to design more effective instructional interventions (Baxter, 1989; Vosniadou, 1999). In many cases alternative conceptions in science may be robust and may resist change (Bisard, Aron, Francek, & Nelson, 1994; Stahly, Krockover, & Shepardson, 1999). Initially,

researchers were interested in confronting and replacing students' alternative conceptions with scientific understandings. However, this approach was not always successful in changing the student's view (Hewson & Hewson, 1988).

More recently, conceptual change has come to be considered an evolutionary process in which there may be a complex interaction between existing conceptual understandings and the learning context (Barnett & Morran, 2002). Various models of conceptual change suggest ways to support and promote scientific understanding in the classroom. For example, Vosniadou and her colleagues stated that naïve understandings, entrenched beliefs, may constrain a student's scientific view. Change may occur over time with multiple experiences and may involve not only cognitive aspects of learning, but may reflect other influences, like the individual's beliefs, motivational needs, learning attitudes, and situational and cultural contexts (Vosniadou, Ionnides, Dimitrakopoulou, & Papademetriou, 2001).

Conceptual change may be facilitated when students participate in a curriculum that provides an experiential base in which students are afforded the opportunity to test and investigate their existing understanding through scientific discourse and meaningful activities (Muthulkrishna, Carnine, Grossen & Miller, 1993). Yager (2005) called for mind engagement in the science classroom that more closely resembles the work of scientists. Students should be formulating questions, designing ways to check one's own question, and communicating findings with others. In response to this line of research, effective instructional approaches might include guided inquiry opportunities, activities designed to foster questioning and planning, as well as time to reflect on science findings. A major goal in science is getting students to think, trust their

thinking, and explain their thinking (Yager, 2005). Effective approaches need to include both hands-on and minds-on work.

Many of the conceptual change studies related to lunar phenomena have identified alternative conceptual understandings that are consistent across ages, varied levels of training, and populations (Trundle, Atwood, & Christopher, 2002). Some researchers have moved beyond describing alternative conceptions and toward identifying strategies and interventions that support students' scientific understandings. There are relatively few studies that examine effective instructional interventions used in elementary school science classrooms. The present study explored using an instructional intervention, which has been successful with fourth-grade children (Trundle, Atwood, & Christopher, 2007a). The current study applied a similar instructional intervention with younger elementary children.

Socio-cultural Aspects

Over the past decades conceptual change approaches that support science learning in the classroom have evolved within a range of theoretical frameworks. Initially, Piagetian stage theory influenced how science learning was conceptualized. Later cognitive psychology and constructivist theory played more important roles (Duit & Treagust, 2003). More recently, conceptual change approaches have taken on a multi-perspective frame, in which the many variables of learning within the science classroom are considered, including student motivation, cultural and social contexts, and intentionality of the student. Research suggests that conceptual change is a gradual, slow reorganization of existing knowledge structures, and that this process can

be initiated, supported, and consolidated in social and cultural environments (Vosniadou & Ioannidis, 1998). The present study focused on conceptual understanding in a particular area, Earth and Space Science, and the change that occurs within that context.

The situational context becomes important in moving learning toward a scientific understanding. The students in this study were encouraged to assume an active, intentional role in the instruction. Learners can be active in the construction of their learning and also intentional. “Learners cognitively engage in the learning process, but also monitor and regulate their learning in a metacognitive manner” (Sinatra & Pintrich, 2003, p. 2).

According to Vosniadou et al. (2001), “concepts are embedded in rich situational contexts, in the tools and artifacts of the culture, and in the nature of the symbolic system used during cognitive performance” (p. 395). Through collaborative data gathering and analyzing, problem solving, planning, and sharing students’ data related to lunar events, patterns and phases over time were documented, analyzed, and described.

Significance of the Study

The *National Science Education Standards* (NRC, 1996) call for children in Grades K-4 to explore and understand lunar concepts, including the observable shapes of the moon and the pattern of movement over time.

By observing the day and night sky regularly, children in Grades K-4 will learn to identify sequences of changes and to look for patterns in these changes...They can draw the moon’s shape for each evening on a calendar and then determine the pattern in the phases over several weeks. These understandings should be confined to observations, descriptions, and finding

patterns. (NRC, 1996, Pp. 131, 133).

The national document further states that children at Grades 5-8 are expected to demonstrate and explain the cause of lunar phases. The *Benchmarks for Science Literacy* (AAAS, 1993) suggests the introduction of moon phases at grades 6-8. Although it is a complex topic, Trundle et al. (2007a) found that fourth-grade children in their study were able to understand and explain lunar phases, sequence of phases, and the cause of the lunar phases after observing and collecting lunar data and exploring the cause of lunar phases using a psychomotor activity (McDermott, 1996). The researchers tempered their positive results by describing the participants as a sample of highly motivated students. The researchers suggested that the study should be repeated with a larger sample of students who represent a broader socio-economic spectrum.

Despite these positive results, other researchers have questioned the appropriateness of teaching complex science concepts to young children (Stahly et al., 1999). For example, Stahly and colleagues suggested that the concept of lunar phases may be too difficult for elementary students, stating that “elementary children are not developmentally and academically prepared for the complex conception of the lunar phase phenomena” (p. 175). Thus, research results at this point are inconclusive and it is too early to draw definitive conclusions about teaching abstract science concepts, such as lunar phases, to young children. Additional research is needed to explore effective interventions that promote understanding of complex lunar phenomena.

More research is needed to determine if the expectations outlined by the national standards are appropriate. Previous research has identified instructional interventions that were effective for pre-service elementary teachers (Trundle, et al., 2002) and

fourth- grade students (Trundle et al., 2007a). Whether the same instructional interventions might be effective with younger students remains an open question.

Research Questions

Most of the research on moon phases has been descriptive, as mentioned earlier. Very few studies, however, have included instructional interventions to promote conceptual change. The needed next step of how to effectively teach young children about lunar concepts is addressed in this dissertation. The research in the present study introduced an instructional intervention related to selected moon phase concepts with elementary children. The specific questions addressed were:

1. What do Primary children know about when the moon can be observed, prior to and after an inquiry-based instruction?
2. What do children know about observable moon phase shapes and sequences before, during, and after inquiry-based instruction?
3. What do children understand about the cause of moon phases before and after inquiry-based instruction?

Limitations of the Study

The study included various limitations that will be reviewed. The participants for this study were selected because of availability. The students were from one self-

contained Primary classroom. Besides the limited number of student participants (21), the majority of this population came from middle-class homes, resulting in little socioeconomic diversity within the group of participants.

Another potential limitation of the study is its design. The research allowed the researcher to be in contact with the participants throughout the day over an extended period of time. The researcher was an insider which can be both beneficial and problematic. Classroom-based research can be a powerful professional development tool for the teacher/researcher. Planning and observing student work allows the researcher to gather information, analyze and reflect on instructional practices that are effective and modify those practices that are not appropriate. Classroom-based research also can be difficult to manage. Since teacher goals and researcher goals can be conflicting, the researcher needed to be aware of her role in the study.

The three-dimensional models representing the sun, the moon, and the Earth used in this study were not to scale for obvious reasons. Inaccuracies in scale may cause misunderstandings related to size of, and relative distances between, the astronomical bodies, the sun, the Earth, and the moon. However, Trundle et al. (2002) found that the models used during pre- and post-interviews did not appear to make a difference in the post-instructional results of that study.

Definitions of Key Terms

In this section some terms used in this study are defined to assist the reader.

Alternative conception – A conceptual understanding that is at variance with the scientifically accepted view (Hewson & Hewson, 1983).

Alternative fragments – A response that includes a subset or subsets of an alternative conception (Trundle et al., 2007a).

Analogical model – Models having one or more of the target’s attributes represented in the analog’s concrete structure (Harrison & Treagust, 1996).

Classroom-based research – A systematic inquiry into classroom analysis of various kinds of data. Generally the researcher is concerned with the qualitative differences among the conceptions that students use to explain scientific phenomena, and the researcher examines students’ topic-related understanding of scientific concepts (Duit & Treagust, 1998). For this study the researcher, the teacher within the classroom of participants, was attempting to contribute to the research base on effective instructional interventions in the science classroom with young children, and to determine the appropriateness of the Earth and Space national standards for this group of students.

Inquiry-based instruction – Instruction that refers to “activities of students in which they [children] develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world...” (NRC, 1996, p.2). For example in this study, guided inquiry-based instruction included participants gathering, recording, and analyzing daily lunar data; formulating questions; predicting patterns; and sharing findings.

Lunar phases – The observable shape of the moon during the synodic period (full lunar cycle or time interval). The representative phases include: the Full Moon, Waning Gibbous, Third Quarter, Waning Crescent, New Moon, Waxing Crescent, First Quarter,

and Waxing Gibbous. The eight scientific labels are commonly used in lunar instruction.

Pattern of lunar phases – One complete cycle of the moon is known as the *synodic period*. The duration of this period is about 29-30 days. Scientists begin documenting the lunar cycle with the New Moon, but for this study we focused on a more obvious shape, like the waxing crescent, to begin our data collection. The *waxing moon* appears to grow, as we see more of the lit half of the moon each day. The *waning moon* seems to shrink, as we see less of the lit half of the moon.

Scientific fragments – Fragments “include a subset, but not all, of the four criteria used to identify scientific understanding” (Trundle, p. 11, 1999).

Scientific understanding of moon phases – Half of the moon is always illuminated by the sun (SciHalf); we see a portion of the illuminated half from Earth (SciSee); the relative positions of the Earth, sun, and moon determine the portion of the lighted half that we see (SciEMS); and the moon orbits the Earth (SciOrb) (Trundle et al., 2007a).

Sequence of lunar phases – The sequence of lunar phases is the regularly observable moon phases during a synodic period. The predictable pattern of lunar shapes is known as the sequence of phases for this study.

Technology-enhanced instruction – Instruction that is facilitated by some type of technology, for example the computer. In this study *Starry Night* (Imaginova version 5.0), a planetarium software program, was used by the participants to gather and record daily lunar data for analysis.

CHAPTER 2

LITERATURE REVIEW

Constructivism

Constructivism as a theory of learning has become a dominant paradigm in the field of education. Within the constructivist perspective it is believed that individuals develop deep conceptual understandings about their world as a result of being active learners. Knowledge is seen as a human construction of the natural world encountered. “Our knowledge about the world is not a mere copy of the reality outside but it is our tentative construction about it,” (Duit, Widodo & Wodzinski, 2007, p.198). In this sense learning is seen not as a transfer of knowledge from a teacher to a student, but something the individual must construct or create, based on observations and existing concepts. According to Fosnot (1996), “constructivism, as a psychological construct, stems from the burgeoning field of cognitive science, particularly the later work of Jean Piaget, the sociohistorical work of Lev Vygotsky...(p. 11)” among others who have studied how individuals learn.

Piaget and Cognitive Development

Constructivism for Piaget, the pioneer of constructivist learning, grew out of dissatisfaction with the current theory of knowledge during the early twentieth century (in the Western world), in which knowledge was conceived as knowing the real world directly as it exists. Piaget’s notion of adaptation helped him reformulate this thinking

into an epistemological theory. In Piaget's theory of knowing (biological in origin), organisms encounter new experiences and seek to assimilate the new sensory experiences into preexisting cognitive structures. If the experience does not fit into existing structures, a perturbation in the individual's mental balance occurs, i.e. a cognitive conflict. Balance is restored by equilibration, either through an assimilation or an accommodation process, which continually forms or reforms knowledge schemas. Schemas evolve as learners interpret and understand knowledge based on "beliefs, values, sociocultural histories, and prior perceptions" (Walker & Lambert, 1995, p.1). Knowledge for Piaget was not a copy of reality, but rather related to the learner's experiential world and the cognitive response to the experience. In Piaget's constructivist theory, "what we see, hear, and feel-that is, our sensory world-is the result of our own perceptual activities and therefore specific to our ways of perceiving and conceiving" (von Glaserfeld, 1996, p. 4).

Piaget knew that knowledge acquisition did not consist of a static body of information being transferred to the learner, but a process that was continually being constructed and reorganized by the learner. Cognitive development to Piaget was described as a global restructuring of the individual intellectually (Carey, 1985). This psychological restructuring is a process of natural intellectual development that proceeds through a series of stages from concrete to abstract thinking. Each stage is characterized by different psychological structures that became more sophisticated, allowing the individual to make sense of increasingly more difficult knowledge. According to this theory, understanding of science concepts may be difficult to achieve until the learner reaches the stage of formal operations, generally in adolescence.

Sociocultural Constructivism

Sociocultural constructivism has its roots in Vygotskian learning theory. Vygotsky, like Piaget, thought learning was constructive and developmental, but Vygotsky emphasized learning through interaction within a community with shared practices, language, and tools. Human cognitive development is rooted in social activity within a culture, or a subculture such as the science classroom. For Vygotsky, language was the primary means of constructing knowledge among and within the culture, allowing individuals control over their mental tasks as they think, plan, and communicate with members of their culture (Vygotsky, 1978). Learning for Vygotsky occurred on two planes, first on an interpersonal (interpsychological) plane through social interactions with others, and then on an intrapersonal (intrapsychological) plane within the individual, as a higher mental function. Vygotsky was critical of Piagetian claims of maturation as a precondition for learning. For Vygotsky, learning was “not development; however, properly organized learning results in mental development and sets in motion a variety of developmental processes that would be impossible apart from learning” (John-Steiner & Mahn, 1996, p. 198).

Vygotsky developed the concept identified as the Zone of Proximal Development to explain the social aspects of learning. The *zone* is the distance between actual development of the individual, as determined through independent problem solving, and the potential development with assistance from a more experienced other (Vygotsky, 1978). In other words the learner may be capable of performing tasks initially with support and then independently.

One principle of Vygotsky's theory of learning is the process of spontaneous and scientific concept development. Concepts that developed naturally, outside the context of explicit instruction, are spontaneous concepts. These everyday concepts, based on an individual's direct experiences, are defined as culturally-shaped understandings and values children bring to school. Scientific concepts, more formal abstractions and more logically defined concepts, to Vygotsky were acquired through explicit instruction in school. These concepts become more meaningful "as they are mediated by an individual's everyday concepts. Everyday understandings are reorganized as a learner develops scientific concepts that allow the child to more systematically define and have deliberate control over his or her everyday concepts" (Sanchez, 2007, p. 16). Vygotsky (1986) recognized the interdependence between the spontaneous and scientific concepts.

We believe that the two processes – the development of spontaneous and of nonspontaneous concepts—are related and constantly influence each other. They are parts of a single process: The development of concept formation which is affected by varying external and internal conditions but is essentially a unitary process, not a conflict of antagonistic mutually exclusive forms of thinking (p. 157).

The situated learning model (Lave, 1991) and the community of participation model (Rogoff, Matusov, & White, 1996) are based on this theory of learning. In these models, participation in a community or situated cognition directly links learning to the context or to its situated nature. According to this perspective, learning is a process of enculturation into a situated social practice where members participate (Lave, 1991). "Participation as members of a community of practice shapes newcomers' identities,

and in the process gives structure and meaning to knowledgeable skill” (Lave, p. 74). In this way specialized skills are developed by the learners through apprenticeship (Rogoff, 1995). Newcomers experience modeling, coaching, and scaffolding by more experienced members of the learning community

Both of these lines of constructivist theory have a strong influence on the way we view knowledge acquisition and how children construct and reconstruct understandings. The idea of conceptual change reflects a constructivist view and provides a framework within which to interpret learning.

Conceptual Change

Learning requires the integration of new information, as well as reorganization of existing understandings (Schnotz, Vosniadou, & Carretero, 1999). This integration and reorganization is generally referred to as *conceptual change*. Conceptual change theories evolved in order to explain shifts or reorganization of conceptual knowledge and have emerged from a constructivist theory of learning. Conceptual change research had “its origins in the misconception research that reached its heyday during the 1980s” (Appleton, 2007, p.511).

More significant contributions to educational theory and practice could be made if scholars understood how conceptual change works. “For decades scholars recognized that conceptual change is at the heart of meaningful learning. Over the years, conceptual change has been represented as a process of achieving structural insight, accommodative learning, understanding of relations, deep learning, or... more recently, mental model building” (Mayer, 2002, p.101). During the 1960s cognitive researchers

tried to develop an overarching theory of learning that would account for student learning, using Piaget's stage theory of intellectual development. By the late 1970s researchers began to challenge the idea of general cognitive structures or cognitive operations to explain student understandings. Many researchers realized the weaknesses in Piagetian explanations of intellectual development and shifted instead to a "focus on domain-specific theories of learning" (Mayer, p.101).

Alternative Conceptions

Most educational researchers agree that children actively construct knowledge about their natural world based on their everyday experiences long before they begin formal education (e.g., Duit & Treagust, 1998; Vosniadou & Brewer, 1994; Vosniadou & Ioannides, 1998). This acquired knowledge is not always compatible with the more formalized analytical information learners receive in school. In some science education research studies, students' non-compatible conceptions have been described and labeled as naïve beliefs and presuppositions (Vosniadou & Brewer, 1992), spontaneous reasoning (Viennot, 1979), preconceptions (Ausubel, 1968), misconceptions (Novak, 1977), and alternative conceptions. In this dissertation, the description of experienced-based explanations will be referred to as *alternative conceptions*, which is a term widely accepted and implies intellectual respect on the part of the learner (Wandersee, Mintzes, & Novak, 1994). The initially preferred term, *misconception*, often gave a negative connotation to the student's understanding. With the latter perspective, the student's mistaken understanding needed to be eradicated and replaced with an accurate scientific idea. With an alternative conception more in-line with the constructivist perspective, students bring an understanding that is contextually rational and valid. The naïve

understanding or preconception can develop or transform into a more fruitful scientific conception.

Alternative conceptions, which are often in stark contrast to scientific knowledge taught in schools, need to be addressed. Within the classroom “meaningful learning does not require only the mere enlargement of information but rather the reorganization of existing conceptions, that is conceptual change, which causes a massive rearrangement in an individual’s cognitive structures” (Mason, 2001, p. 306). These conceptions may be very resistant to change; in fact, even instructional interventions introducing scientifically accepted information have failed to resolve erroneous alternative concepts. The introduction of an additional concept can result in the creation of a *hybrid* explanation for a science concept, combining elements from both the alternative and the scientific concept, in order to make sense of the content or principle.

In a comprehensive bibliography of alternative conception research, Pfundt and Duit (1991) referenced approximately 2000 studies that could have an impact on the quality of teaching science education. Wandersee et al. (1994) summarized the findings from the seminal studies in this bibliography coming from the science education literature, and identified eight knowledge claims that emerged from the research:

1. Learners come to formal science instruction with a diverse set of alternative conceptions concerning natural objects and events (p.181).
2. The alternative conceptions that learners bring to formal science instruction cut across age, ability, gender, and cultural boundaries (p. 185).
3. Alternative conceptions are tenacious and resistant to extinguish by conventional teaching strategies (p.186).
4. Alternative conceptions often parallel explanations of natural phenomena offered by previous generations of scientists and philosophers (p. 186).

5. Alternative conceptions have their origins in a diverse set of personal experiences including direct observation and perception, peer culture, and language, as well as in teachers' explanations and instructional materials (p. 188).
6. Teachers often subscribe to the same alternative conceptions as their students (p. 189).
7. Learners' prior knowledge interacts with knowledge presented in formal instruction, resulting in a diverse set of unintended learning outcomes (p. 190).
8. Instructional approaches that facilitate conceptual change can be effective classroom tools (p. 191).

Alternative conception research highlights the idea that both students and teachers hold alternative conceptions and that these conceptions can be robust and difficult to change. This body of research tended to identify commonly held notions, but did little to promote scientific understandings.

Understanding how initial concepts about our natural world develop and how those ideas change, as children learn, has been studied widely since the early 1980s by two independent research traditions, the science education perspective (Beeth, 1998; Posner, Strike, Hewson & Gertzog, 1982) and the cognitive development science perspective (Carey, 1985; Vosniadou, 1994; Vosniadou & Brewer, 1992, 1994). Each perspective has its own view of change within the constructivist paradigm. The constructivist research on conceptual change in science education focused on applied research. This body of research typically addressed educational practices and materials that would support or promote change. The cognitive developmental researchers tended to focus on the individual and the cognitive structures that changed when learning occurred. By the 1990's there was a shift in cognitive developmental research that addressed applied principles of conceptual change (Duit & Treagust, 2003). This

turn or bridging of the two research traditions holds “powerful means to improve science teaching and learning” (Duit & Treagust, p.682).

Science Education Perspective of Conceptual Change

One line of conceptual change research has its roots in science education. Since the 1970s, science education researchers have relied less on Piaget’s notion of viewing the learner at a particular stage in cognitive development, and instead have focused more on what the learner brings to the task in the way of existing knowledge and intuitive framework of assumptions (Chi, 1992).

This group of researchers has produced a body of information on learners’ intuitive concepts or alternative concepts. During the cognitive revolution of the 1970s and 1980s science education researchers, including Novak (1977) and Viennot (1979), brought attention to the fact that students bring alternative conceptions to science learning that are often “robust and difficult to extinguish through teaching” (Vosniadou & Ioannides, 1998, p. 1213). Vosniadou and Ioannides highlighted the need to “pay more attention to the actual content of the pupil’s ideas and less on the supposed underlying logical structures” (p. 1213). Research and theory building in the science education field focused on finding a way to conceptualize science learning. Many science education researchers turned to the philosophy and history of science as a major source in explaining conceptual change. Researchers developed an analogy between Piaget’s idea of assimilation and accommodation and the science field’s concept of *normal science* which was put forth by Kuhn (1970) to explain theory building or theory replacement in the science domain. This analogy led to the ‘child as the

scientist' approach (Posner et al., 1982). Posner and his colleagues developed an instructional theory to promote conceptual change in student learning, which will be discussed in the next section. This theory was called the Conceptual Change Model and has influenced research in the science education field significantly.

The Conceptual Change Model

Conceptual change studies first appeared in the early 1980s with the work of Posner et al. (1982). This body of work was influenced by Kuhn (1970) and other science historians and philosophers of the time, and was based on Piaget's notion of accommodation or radical change. According to Posner et al., "learning is the result of interactions between what the student is taught and his current ideas or concepts," (p. 211). The four conditions related to conceptual change in this approach were derived from the work of Kuhn (1970), Lakatos (1970) and Toulmin (1972).

Views in science at that time highlighted two distinguishable phases of conceptual change (Kuhn, 1962). One phase was *central commitments* in science, which was the definition of problems, strategies, and solutions to solve the problem that defined the *normal science* or *paradigm* (Kuhn, 1962). Normal science consisted of a set of shared beliefs, assumptions, commitments and practices within the science field, which were based upon "past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice" (p. 10). Normal science continues for the scientist until anomalies occur. The second phase in theory change involves modification of the central commitments or challenges to the current way of thinking about the solution. This involves scientists looking for a new way of seeing the world. Kuhn called these new

views *scientific revolutions* (1962). In order for a theory to be accepted as a paradigm, it must appear more firm than its competitor. For example, Posner et al. (1982) suggested that a new way of thinking needs to be rational and intelligible before it is accepted. Scientists then use a particular paradigm and conduct science using that paradigm. When a paradigm no longer seems useful for explaining empirical observations, then a new conceptual understanding or theory is formed. This gestalt shift in theory brings about resolution within the scientific field.

Posner and his colleagues (1982) felt that the theory refinement process utilized by scientists could be applied to conceptual change theory in science education. These ideas could guide the way students deal with new scientific information that is different than their beliefs and assumptions. Through the processes of assimilation or accommodation (Piaget, 1974), students either would rely on current scientific concepts or would reorganize existing concepts to promote understandings. Assimilation of scientific understandings refers to the student's integration of preexisting concepts and new phenomena. Often, according to Posner et al., the student has adequate knowledge of the topic in order to grasp new concepts. Posner et al. suggested that at other times, a more radical accommodation of information is necessary. Even with radical accommodation, Posner et al. state that not all concepts are replaced, which will be discussed further in the next section.

Posner et al. (1982) developed a theory of misconceptions or alternative conceptions that became influential in science education research. According to Posner et al., the framework for conceptual change related to replacing old concepts with new ones that serve the learner better. Posner et al. were interested in identifying students'

underlying conceptions or the actual content of their ideas, and understanding some reasons these conceptions were persistent.

The Conceptual Change Model had two central tenets, that of status and that of conceptual ecology. As Posner et al. (1982) put forth, an idea must be plausible (credible), intelligible (comprehensible), and fruitful (useful) in order to establish status for the learner. The greater a concept is understood, is useful and is credible, the higher the status of the concept. High status concepts are well formed and have coherence. Conceptual change may occur only after the preexisting concept has a lower status than the newly formed concept (Hewson & Hewson, 1983).

Conceptual ecology refers to the epistemological and ontological commitments and beliefs that are held by the learner. These commitments, the individual's current concepts, can serve as a measure to judge any new information. The concepts that hold up, or are valid for the learner, are the ones that help the learner resolve anomalies. *Cognitive artifacts*, or the kinds of concepts (Strike & Posner, 1992), can be examined to measure an individual's conceptual ecology and include:

Anomalies – Problems that create dissatisfaction with a concept.

Analogies and metaphors – These may assist in understanding a new concept.

Epistemological commitments – Subject matter or view that the science field counts as a valid explanation for specific phenomena.

Metaphysical beliefs and concepts – Understandings that are known about the nature of the universe, which are beyond direct empirical challenges.

For example, beliefs about *absolute space or time* can have a metaphysical quality.

Other knowledge – Knowledge from other fields and competing concepts
could be judged to show more promise than existing concept.

Ecologies may either help or hinder instruction, so knowing the individual's conceptual ecology would be important when conceptual change is needed. The conditions related to conceptual ecologies, including dissatisfaction, intelligibility, plausibility, and fruitfulness, will be discussed next.

Posner et al. (1982) theorized that four conditions must be satisfied in order for radical conceptual change to occur, i.e., for one concept to replace another. One of the conditions that promote radical accommodation for both students and scientists is *dissatisfaction* with an existing concept. A radical change in conceptual belief is unlikely for either students or scientists unless the preexisting concept has failed to serve any purpose for the science task. If less radical changes to the concept are not working, then accommodation may be a consideration.

A new concept presented must be *intelligible* for the student. In other words the student must find the concept clear, understandable, and non-contradictory. In addition, the student must identify or construct a coherent representation of the concept, which implies a deeper understanding of the concept. Information must fit into this new representation. "How one represents knowledge and theories determines one's ability to make sense of and use the new ideas" (Posner et al., p. 217).

Initial *plausibility* is another condition necessary for radical accommodation to occur. The new concept needs to be reasonably aligned with current thinking. Besides knowing what the concept means, it must be believable to the learner. According to

Posner et al., one needs to find the concept consistent with other theories and knowledge, as well as with past experience. It needs to be useful in solving anomalies for the learner.

Finally the new concept should be *fruitful* or have the potential for application. One should be able to apply the new understandings to various problems. In this way the new concept should have the potential to be used in a variety of science inquiries and open new ways of extending understanding to novel problems.

This model developed by Posner et al. (and expanded by Hewson, 1982) is aligned with instructional theory and how best to teach science in order to promote conceptual change. It has been influential in the science education field, guiding much of the research in the 1980's and the early 1990's.

Hewson and Hewson (1984) emphasized that competing concepts may not create an overwhelming sense of dissatisfaction for learners. When this occurs the learner may adopt the concept that possesses a higher status. Hewson (1981) termed this event *conceptual capture* instead of conceptual change. Interestingly, the replaced conception could be reinstated at another time, suggesting that the newer concept was not truly internalized.

New Perspectives in Science Education

The social aspects of the knowledge construction process have traditionally been neglected. Most of the science education research throughout the 1980's and early 1990's focused on the individual's construction of knowledge and put little, if any, emphasis on contextual factors or other supporting conditions. The process of science learning is no longer viewed as a pure initial conceptual change theory. More than a

logical explanation of the scientific view is needed in order for conceptual change to occur. According to Duit and Treagust (1998), those who study and consider science education have now taken more of an inclusive view of science learning. “Although individuals have to construct their own meaning of a new idea, the process of constructing meaning always is embedded in a particular social setting of which the individual is part” (p.8). The view of making meaning has shifted from an internal cognitive perspective to a perspective that is more reliant on social influences, highlighting both the social and the individual. Vygotsky’s theory of learning emphasizes the importance of the social and the context influences in the science classroom. Motivational constructs, such as goal-setting and metacognitive strategies, are supporting conditions that may help the student become more responsible for his/her learning in science, according to Sinatra and Pintrich (2003). The Intentional Conceptual Change model, which includes many of these constructs, will be addressed later.

Over time most of the tenets of Posner et al.’s theory have been questioned. Socio-cultural theorists point out that conceptual change occurs within a cultural, situational context. It is not only an internal cognitive process, but a social one, as well.

While Posner et al. focused on the rational, logical process of conceptual change, Sinatra and Pintrich (2003) suggested there may be other factors that promote or obstruct conceptual change, like motivation, metacognitive awareness, affective measures, beliefs and attitudes. Intentional constructs controlled by the learner and situational context all play an important part in the acquisition of knowledge.

Changes occur gradually and over time. This understanding has been demonstrated convincingly and is in opposition to Posner et al.'s idea of gestalt shift which happens in a short time frame (Vosniadou, 2007). Vosniadou and Brewer (1992, 1994) feel that knowledge is slowly transformed by the learner, as he/she refines existing conceptions into new or newly restructured knowledge. This knowledge transition can vary in length, and even when restructuring is finalized, the new conceptions may not replace the old. The prior conception may continue to exist (Sinatra & Pintrich, 2003).

Others have pointed out that changes in concepts do not need to be considered a replacement of the alternative concept. The Posner et al. model focused on the incompatibility of two distinct but well-organized concepts. One of the concepts in this model needed to be extinguished in favor of the other. Instead of replacing one concept with another, conceptual change is believed to be a slow, gradual revision of the initial concept (Vosniadou et al., 2001).

Cognitive conflict, as a pedagogical strategy supported by Posner et al. does not always result in conceptual change. According to Duit and Treagust (2003) no study has demonstrated that a student's conception could be completely erased and replaced by scientific knowledge. Most studies showed that the old concepts were still with the student and could even be used depending upon the context. These competing concepts may interact to become hybrid conceptions.

Duit (1999) argued that the *student-as-the-scientist* metaphor does not work. The scientific community and the science classroom community are very different. “[They] are operating on the grounds of fundamentally different aims and within

fundamentally different institutional conditions” (p. 265). Schools need to “maintain bureaucratic norms”, while the scientific community is more interested in “maintaining scholarly norms” (p. 265).

Revision of the Conceptual Change Model

In reaction to the criticism of the initial conceptual change model, Strike and Posner (1992) revised the model to include a wider range of ecologies that the learner may hold. They advocated for uncovering these ecologies and discovering how the ecologies might inform student learning. The authors also saw the initial theory as being too rational, possibly as a result of using the philosophy of science to guide the development of the original model. The revised model reflected more of the social and affective factors that can influence conceptual change. Another concern with the initial model was the neglect of the interaction between prior and new conceptions (Duit, 1999). The revised model suggests that these interactions are dynamic and ever evolving.

Strike and Posner (1992), in their attempt to revise the initial model, suggested that:

A wider range of factors needs to be taken into account in attempting to describe a learners’ conceptual ecology. Motives and goals and the institutional and social sources of them need to be considered.

Current scientific conceptions and misconceptions are parts of the learner’s conceptual ecology. Thus they must be seen in interaction with other components.

Conceptions and misconceptions can exist in different modes of representation and different degrees of articulateness.

A developmental view of conceptual ecologies is required.

An interactionist view of conceptual ecologies is required.

Cognitive/Developmental Conceptual Change Research

At the core of science education approaches to conceptual change is the view that knowledge construction is a process of sense-making within the natural and social environment. Conceptual change is thought of and written about as a major restructuring of already existing knowledge. This is different than conceptual growth, which enriches and enlarges prior knowledge. Reference to Piaget's assimilation and accommodation, with accommodation being the major restructuring of knowledge, can be seen in Carey's (1985) distinction between weak restructuring and radical restructuring, and Vosnidou's theory enrichment and theory revision to be discussed in this section of the paper.

Up to the 1980's cognitive/developmental researchers were influenced by Piaget's stage theory, based on global changes within the developing individual. Piaget explained that changes occur within the logical structures of thought as the child develops. Reasoning and acquiring knowledge were thought to be stage-specific. "Conceptual change was described as domain-general modifications of cognitive structures that affect the knowledge acquisition process in all subject-matter areas," (Schnotz et al., 1999, p. *xiii*). However, research empirically showed that children performed higher and were more cognitively capable than Piaget thought (Novak, 1977). Novak cautioned science educational researchers not to wear "conceptual

blindness” when it came to using Piaget’s stage theory to explain science learning. He cited an increasing number of studies that demonstrated:

A small but significant number of young (5-7) year old children can consistently perform very *formal* thinking.

There is a gradual increase in the percentage of youngsters that perform formal (abstract) thought from grade one to adulthood.

A substantial fraction (up to 60%) of some adult groups fails to show consistently formal thought.

Almost any given child may demonstrate *all* Piagetian stages on different occasions with different materials throughout his developmental period (5-16+ years).

Variability in *stage* of thinking appears to be strongly related to socioeconomic status, parent’s occupation, specific instruction of high quality, and numerous other environmental factors.

For a given child observed over a range of activities or for groups of children observed over a range of years, numerous stages and/or substages are necessary to categorize the performance (p. 394).

Novak (1978) challenged the focus on Piagetian developmental intellectual stages in the research. He felt that student learning was less dependent upon general cognitive structures or cognitive operations to make sense out of experiences. Instead, Novak felt that students developed a hierarchical organized framework of specific concepts to make sense out of the experiences. He argued that if cognitive development, maturation, occurs spontaneously, then we should see similar concept development across same-age children. Of course, that does not necessarily happen. This challenge within the cognitive science research gave way to addressing the ways in which students construct

science knowledge in specific domains. Cognitive developmental conceptual change research will be discussed next in terms of domain-specific knowledge.

Domain Specific Knowledge

The findings in cognitive research demonstrated that children were cognitively capable, sometimes beyond Piagetian expectations. Carey (1985) was interested in exploring the idea of specific domain approaches to learning. Carey suggested that conceptual change might be more related to domain-specific content learning rather than global restructuring, which signified a shift in cognitive developmental researchers' thinking. As was cited previously, up until this time there was a significant reliance on Piaget's stage theory to explain the changes in logical thinking and assimilating new information. In Carey's view, children begin with some theory-like conceptual structures within specific domains of knowledge. Either through formal or informal learning these conceptual structures become more defined and interrelated. As the child's system of theory-like structures multiply and deepen or embed, the structures change. This change is seen as an increase in knowledge within a domain. This way of thinking about knowledge acquisition is the result of experience or instruction, as opposed to the result of the individual's logical capabilities (Vosniadou & Ioannides, 1998).

Phenomenological Primitives

diSessa (2002) saw the need to develop a more explicit method of theorizing how learning changes for the individual. Conceptual change theories and models were fraught with vagueness and lack of accountability from the research community. Cognitive researchers in his estimation needed a more refined view of learning in order to understand the differences in individual's difficulty or ease involved in conceptual change. diSessa suggested that alternative concepts consist of fragmented knowledge bits that do not have coherence, typically attributed to a theory or a theory-like structure. diSessa defined the individual's complex knowledge system by considering the smallest mental entity. There are a great many and various types of these entities that are classified or categorized into thought. This range and diversity can account for the complexity in conceptual change. For example, one concept can include thousands of knowledge elements.

By actively selecting elements, depending on the context of the action, a concept can be invoked as a whole. These elements diSessa called phenomenological primitives or p-prims and are sub-conceptual pieces loosely coupled. They are fluid entities with no sense of a system. These context-dependent "p-prims" can be activated and aligned for concept development. By integrating pieces (coordination classes) of knowledge into a whole, new ideas or knowledge can be acquired.

In contrast to diSessa "some researchers who focus on cognitive aspects of learning (Chi, 1992; Chi & Roscoe, 2002; Vosniadou, 1999) think that children organize some of their experiences in narrow but relatively coherent framework and

construct specific theories in their attempt to make sense of the physical world” (Ucar, 2007, p.38).

Ontological Categories

Chi (1992) references conceptual change as a mechanism responsible for meaningful learning to occur. This process happens when the learner moves from a naïve understanding (alternative concepts) to a more scientific view of understanding. Chi explains the change in terms of category status. In Chi’s view, all concepts belong to a major category of concepts and “ontological categories” are a subset. Concept change within an ontological category is referred to as “conceptual change.” If a concept moves across categories, Chi refers to it as a radical conceptual change.

Ontological knowledge is basic knowledge one develops about our natural world. This knowledge is divided into conceptually distinct categories that can be retrieved easily. Chi proposes that there are three major categories that are distinct physically and psychologically. This model is characterized as *trees* with each tree containing categories and subcategories of concepts that are related hierarchically and laterally to each other, depending on attributes of the concept. The three main categories are matter (or material substances), events, and abstraction. Category assignment is organized by attributes in intrinsic ways (i.e. property of behavior) or psychologically.

When an individual assigns a concept to a category, this new concept reflects the attributes given to that category. From this perspective, a misconception can be seen as a miscategorization of the concept. Chi (1992) makes two assertions:

1. Conceptual change within an ontological category requires a different set of processes than across ontological categories,
2. It may be inappropriate to think of conceptual change across ontological categories as change at all. This kind of radical change may be the development of new conceptions with initial conceptions remaining more or less intact (p. 192).

The less radical conceptual change within the *tree* model may be a simple reassignment of the concept. As the concept evolves and the learner acquires more attributes related to the concept, the concept may *migrate* to a more salient position within a category. Chi refers to this migration as reorganization of the concept.

Radical conceptual change across categories for Chi (or moving concepts from tree to tree) is considered a reassignment of concepts. This is more difficult to accomplish. The initial concept may never be extinguished, in which case the new concept may be learned and assigned to a new category on another tree system while the original concept continues to remain on the original tree. “One of the major occasions for needing radical change is in the learning of science concepts,” (p. 139). In order to affect change, Chi suggests that learners must be told explicitly about the concept, as well as have experiences using the concept in context. Learners must reassign concepts through conscious abandonment of preexisting concepts, or they may allow the two concepts to coexist.

Chi (1992) asserts that neither type of conceptual change (within or across ontological categories) is a simple process. Conceptual change within ontological categories happens with more frequency than radical conceptual change. When radical conceptual change occurs the outcome is more dramatic.

Framework Theory

According to Vosniadou (2002) children begin acquiring knowledge and organizing this knowledge into intuitive, narrow but coherent frames based on everyday physical experiences. Knowledge acquisition begins in infancy (Spelke, 1991) and is based on these physical world interactions. Spelke defined five constraints related to how physical objects behave that appear to be noted by infants. These constraints are continuity, solidity, no action at a distance, gravity, and inertia. Vosniadou et al. (2001) believed that these constraints form the foundation for initial concepts around which new information will be judged and organized. In this perspective, knowledge is not unstructured fragments or knowledge elements (diSessa), but a system or a framework of beliefs (based on observation and somewhat easy to change), presuppositions (deeper theoretical constructs and more difficult to change) and mental models that the child uses to explain new information received (Vosniadou, 1999, p.8).

Vosniadou (1994) refers to this system as a *framework theory*. These theories are used to denote a system of ontological and epistemological presuppositions with some coherence, as opposed to scientific theories which are highly systematized and testable. Ontological presuppositions refer to elements in nature we think exist and epistemological presuppositions are presuppositions related to the nature of knowledge. However, the framework theory is “not available to conscious awareness and hypothesis testing” (Vosniadou, 1994, p.48). Vosniadou found that in the process of learning science these presuppositions based on intuitive knowledge of the physical world may act as constraints, when introduced to scientific knowledge. These early understandings may limit the knowledge that one accepts, if the new insights are at odds with existing

knowledge. This can happen because the “scientific explanation of physical phenomena often violates fundamental principles of intuitive physics which are confirmed by everyday experiences” (Vosniadou et al., 2001, p.384).

Within framework theory, Vosniadou and Ioannides (1998) assumed that children also create *specific theories*, in order to explain phenomena. These “specific theories consist of beliefs that give rise to mental representations or mental models, under the constraints of the presuppositions of the framework theory” (p.1216).

Vosniadou and Ioannides explain that specific theories have a set of beliefs that are under the constraints of the framework theory. Both framework theories and specific theories guide the child in developing mental models to explain the concept. According to this perspective, Vosniadou and Brewer (1992) used the construct of *mental models* to represent the ideas individuals hold about the physical world. There are three mental models: the initial mental model, the synthetic mental model, and the scientific mental model. Each model is a dynamic structure that can be formulated on the spot and manipulated by the individual to problem solve and interpret situations. These models provide information about the individual’s underlying knowledge base.

The *initial mental model* is constructed by the individual early in childhood and is based on observations of his/her physical world. These models are not influenced by adult culture or formal scientific instruction. Like diSessa, Vosniadou and Brewer (1992) agreed that the naïve knowledge related to physics is not formed into a single frame that can be replaced quickly when children are exposed to scientific knowledge. Vosniadou and Brewer appreciated diSessa’s explanation of how knowledge develops gradually over time. However, Vosniadou and Brewer believed that these naïve

systems of knowledge do have coherent explanatory structures that support explanations about their world. New information that is consistent with prior knowledge may be incorporated more simply. However, when information is contrary to prior knowledge, learning may be more of a challenge. Naïve framework theories can hinder future science learning, especially when currently accepted science explanations are very different from the child's everyday experiences. For example, Vosniadou and Brewer (1992) found that children in elementary school had difficulty creating the representation of the earth's spherical shape. The round shape violated their preexisting conceptions of the flat earth. Because of entrenched ideas, many of the children in the study represented the earth as a flat rectangle or a pancake-type disk.

The *synthetic mental model* is a model created to reconcile the individual's presuppositions about the world and the information the individual is receiving from adult culture and/or instruction. Children try to assimilate new information they receive with their existing knowledge schema. In the same study Vosniadou and Brewer (1992) noted that children explained the shape of the earth by proposing a "dual earth" representation. One earth is flat, the one we live on, and the other is the spherical planet in space. This misconception demonstrated that children using this concept were trying to incorporate new scientific information into their preexisting beliefs. Vosniadou and Brewer found that there were levels of revision within the synthetic mental model, which suggested there may be a progression from simplistic to a more advanced model that evolves when children continue to revise their thinking, and that this revision is a slow, gradual process. There are different degrees of concept entrenchment, which explains why some concepts are more difficult to change.

Scientific mental models are described as culturally accepted models, representing currently accepted scientific views. These scientific mental models may not be fixed, but may be challenged with the introduction of new knowledge. “Eventually [children] need to be helped to create larger theoretical construction that have greater explanatory adequacy and also achieve the flexibility needed to take into consideration other points of view” (Vosniadou et al., 2001, p. 391). The process of changing from an initial mental model to a scientific mental model is gradual and gives rise to the construction of synthetic models as children interpret and reinterpret their presuppositions within a new frame, leading to the scientific model.

Instructional Considerations

Intentional Conceptual Change

Early cognitive developmental research has provided detailed descriptions of a variety of internal cognitive processes that occur during conceptual change (Carey, 1985; diSessa, 2002; Vosniadou et al, 2001), as well as situational and social factors that may influence change. Science education research has explored the external factors that may facilitate change, such as instructional activities, the teacher, format of the instruction. Sinatra and Pintrich (2003) found that even when situations are well designed to promote change, learning does not occur because of learner characteristics, like “motivation, affective resistance, and learner’ beliefs” (p. 2). In other words knowledge construction is often out of the learner’s *impetus of control*. Sinatra and Pintrich see intentional learning as a way to mediate both the internal processes and the external factors related to conceptual change.

Intentional learning is interpreted in a variety of ways, but most describe it as a “state of mind or a level of cognition that is to be distinguished from unconscious or automatic thought and / or behaviors,” (p.3). The basic understanding of intentional processing of knowledge is that it is goal-oriented and directed or guided by the learner. Actions by the learner are strategic, self-regulated, and deliberate. Vosniadou (2003) argued that conceptual change is possible without intentional learning, however, the learning is “less adequate” (p.377). When intentional, purposeful learning is not used; new concepts may be unstable and full of inconsistencies. In other words the concepts may not be under full conscious control of the learner. Vosniadou claimed that many of the intentional learning constructs, like metaconceptual awareness, self-regulation, motivation to engage in the work, and critical thinking, are key factors in both cognitive developmental research and science education research. Unlike Sinatra and Pintrich (2003), Vosniadou suggested that intentional learning is not something that develops spontaneously, but is “something that develops with age and is affected by schooling, although not necessarily by the nature of instruction that goes on in many schools,” (p.379). Intentional learning can be facilitated by schooling.

Metaconceptual Awareness

Children need to become aware of their existing understandings related to science concepts. As children begin the slow process of revising their initial conceptions, they need opportunities to share their theories. Sharing existing knowledge will allow individuals to check their hypotheses against evidence gathered through experimentation or others’ understandings. Children may need support revising

their larger theoretical frameworks, as well as specific theory frames. Teachers can take student understanding into consideration when designing learning opportunities that may challenge alternative conceptions. Open discussion within a group setting provides a forum for active engagement and opportunities to make thoughts overt. Discussion opportunities allow students to share personal points of view, reflect on and evaluate their thinking, and question explanatory frames they hold. The evolutionary process of conceptual change begins with discourse, as students formulate, reformulate, and test their knowledge through meaningful activities and interactions within a learning environment.

Vosniadou and Kollias (2003) suggested other factors that may assist students in their learning, like providing collaborative work situations, using observations to test personal beliefs, learning how to use evidence to evaluate personal conceptions. Vosniadou and Kollias emphasized that understanding, over memorization, and inquiry, over learning by authority, should be encouraged in the science classroom. The atmosphere should create positive beliefs and attitudes about science knowledge.

Pedagogical Concerns

Vosniadou and her colleagues (2001) suggested that fewer science curriculum topics or less breadth, focused on deeper exploration or more depth within a specific domain, may offer a more qualitative understanding of the science concept. Besides the breadth of curriculum being a concern, Vosniadou et al. proposed considering the order in which concepts are presented and students' prior knowledge when designing effective, meaningful curriculum. The concepts within a specific domain have

relational structures that may support or influence learning for the student. For example, Vosniadou, et al. stated that the challenges students face when learning about the spherical shape of Earth and where people live on Earth is based on their understanding of gravity. That is, students would have difficulty understanding that gravity is directed toward the center of the Earth, if they do not grasp the spherical shape of the Earth. These two concepts are closely related. Barnett and Morran (2002) suggested that children may have difficulty understanding the phases of the moon and what causes the phases, if they do not understand how light moves and reflects off of the moon's surface. Another important concept for understanding the phases and causality of phases is the relative size, motion, and distances between the sun, Earth, and moon (Barnett & Morran, 2002).

Social and Cultural Factors

In the past, cognitive/developmental psychologists were interested in what occurs within the individual as new information was interpreted. Research generally focused on the mental processes and intellectual activity involved in learning. Presently, there has been a shift to examine the external factors that influence learning, as well. Situational and cultural contexts have become more important when trying to understand how to facilitate conceptual change for the student.

In examining the role of situational context and of culture within the learning environment Vosniadou et al.(2001) analyzed the verbal interactions of students and teachers and provided a description of “the internal representations and processes that go on during cognitive activity” (p.393) within a fifth-grade science classroom in

Athens. Specifically, the researchers looked at how communicative interactions and the use of tools and artifacts of the culture influence conceptual change. The experimental group worked in small groups on various activities that would be developed into class presentations. The students were encouraged to discuss ideas openly and question others' ideas. The control group received regular instruction in mechanics as outlined in the national curriculum. Teacher strategies varied between the experimental and control groups. During the instructional intervention conducted by the researchers, multiple interviews were given so that learning changes could be evaluated at many points. Transcribed videotapes, pre- and post-tests were given, as data sources. Vosniadou et al. found that within the experimental class situation the teacher asked more questions, asked for clarification and evidence which engaged children in a more critical dialogue, and used empirical observations to lead children into explanations of their thinking. The children within this setting demonstrated statistically significant gains in science learning, when compared to the control group.

Vosniadou stated that most conceptual change researchers believe the change process happens not solely in the minds of individual learners, but rather within a community.

Vosniadou's Influence

Five constructs within Vosniadou's model that show consistency throughout her research and were used to guide this classroom study are:

1. Conceptual change develops gradually, through revisions and refinements of new informational elements being introduced to the learner.

2. Children are active learners and participate in the construction and the planning for that learning.
3. Learner's preexisting concepts can both hinder and support future science learning.
4. Children hold narrow but coherent concepts about their physical world. Interrelated observations, beliefs, and presuppositions that form relatively coherent explanatory frames.
5. Science learning does not happen in a vacuum. There are social and cultural factors that may support learning.

The present study reflects the conceptual development perspective that Vosniadou sets forth. Young students explored lunar phases and the cause of lunar phases through participation in a collaborative environment. Primary children, influenced by moon observations over periods of time and children's literature that may misrepresent lunar phases, may bring non-scientific knowledge to the formal experience. Based on previous research, the naïve knowledge may satisfy their understanding of the natural world and may be resistant to change. Active, intentional participation in gathering, recording, and analyzing lunar data may help students refine and revise non-scientific understandings. Instructional intervention based on *Physics by Inquiry* (McDermott, 1996) which provides guided student inquiry, may support conceptual change of existing non-scientific concepts. Guided student inquiry provides opportunities for students to compare their understandings (conceptual framework) about lunar phases and the cause of lunar phases against scientific concepts. In summary, the five constructs articulated by Vosniadou served this study.

Lunar Phase Concepts

As noted in the previous review of the conceptual change literature, several studies indicated that students come to formal science instruction with personal knowledge systems as a result of everyday experiences, and much of the time those systems, including those about astronomical phenomena, are in stark contrast with scientifically accepted views (Driver & Easley, 1978; Viennot, 1979). These alternative conceptions, or conceptions that are at variance with the accepted perspective in science, have been the focus of much research. Pfundt and Duit (1998) cite 116 studies that address alternative conceptions related to astronomical events. Lunar phase research is an important aspect of these studies. Astronomical objects and events were investigated in a variety of ways and across diverse populations. Much of the research is descriptive, such as the survey studies that identify alternative conceptions related to lunar knowledge (Bisard et al., 1994; Dai, 1991; Dunlop 2000: Philips 1991; Schoon, 1995). Other types of descriptive studies include interviews that explore what participants understand (Baxter, 1989; Sharp 1996), and classroom interaction studies (Abell, Martinii, & George, 2001; Abell, George, & Martini, 2002; Suzuki 2002). The conceptual change studies focus on changes in student knowledge or skills after an intervention has been introduced and implemented (Barnett & Morran, 2002; Stahly et al., 1999; Trundle et al., 2007a). Both the descriptive and conceptual change studies cover a range of age groups including inservice teachers (Parker & Heywood, 1998), preservice teachers (Mulholland & Ginns, 2007; Trundle et al., 2002), high school (Trumper, 2001b), junior high school (Trumper 2001a) and elementary students (Barnett & Morran, 2002: Stahly et al., 1999: Trundle et al., 2007a).

Policy Documents

Policy documents such as the *National Science Education Standards* (NRC, 1996) and the *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS] 1993) inform or act as a framework for designing scientific explorations and opportunities for students to extend and develop understanding and knowledge in the Earth Science domain. For example, part of scientific literacy recognized in the *National Science Education Standards* (NRC 1996) includes the importance of understanding lunar concepts. Grades K-4 Earth and Space science standards emphasize the patterns of movement and shape changes in the moon. The document states:

By observing the day and night sky regularly, children in Grades K-4 will learn to identify sequences of changes and to look for patterns in these changes....They can draw the moon's shape for each evening on a calendar and then determine the pattern in the phases over several weeks. These understandings should be confined to observations, descriptions, and finding patterns (p. 130).

Trundle and her colleagues (2007a) pointed out that the standards suggest “observing, describing, and finding patterns in moon shapes, or phases, is less conceptually demanding and more developmentally appropriate for younger children than explaining the causes of the moon phases” (p.596). In other words, the Grade K-4 science standards are focused on observations and descriptions.

The Grade 5-8 standards are more demanding and expect children to find evidence of the changes, as well as determine causal explanations for the phenomena. The *National Science Education Standards* state that “by Grades five through eight,

students have a clear notion about gravity, the shape of the earth, and the relative positions of the earth, sun, and moon. Nevertheless, more than half will not be able to use these models to explain the phases of the moon” (NRC, 1996, p. 139).

The *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS] 1993) state that the study of causes of moon phases should occur in grades 6-8:

The benchmarks here call for students to be able to explain two phenomena- the seasons and the phases of the moon- that are usually not learned well. Most adults are unable to give even approximately correct explanations for them. Most students are told by teachers what causes the seasons and the phases of the moon, and they read about them without understanding. Moon phases are difficult because of student unfamiliarity with the geometry of light and ‘seeing’. To help figure out the geometry, student can act out the sun-earth-moon relationships and make physical models (AAAS 1993, p. 66).

Both the National Research Council (1996) and the American Association for the Advancement of Science (1993) acknowledge the complexity of the lunar phase concept.

Moon Research

The scientifically accurate explanation for the cause of lunar phases includes the following: that “despite half of the moon being illuminated by the sun at all time, the portion of that half that can be seen from Earth - what we call the phase - depends upon the relative positions of the sun, Earth and moon” (Bailey & Slater 2003, p.5). Suzuki (2002) explains phases as *apparent changes* that are caused by the position of the moon with respect to the sun and Earth. “We see varying portions of the side of the moon that is lit by the sun,” (p. 893). Understanding the cause of moon phases can be challenging,

Suzuki points out. It involves “thinking in three dimensions from two perspectives” (p.893). One perspective would be viewing the moon from Earth (our perspective), and the other requires one to infer what would be seen when looking down on the sun, Earth, and moon from a point in space above the solar system.

During the active lifespan of an individual there are multiple opportunities to experience lunar phases both informally through direct observations in the physical world and formally within structured learning situations. With each new bit of incoming information the learner interprets or tries to give meaning to an already existing knowledge frame. A variety of changes may occur, when new information is first encountered. New information may be integrated into a preexisting knowledge or cognitive frame where the old and new information may undergo reorganization or restructuring (assimilation or accommodation); the preexisting cognitive framework may be replaced with the new information while the old information may be lost or fade temporarily; or the new information may be rejected (Stahly, et al., 1999).

Vosniadou’s (e.g., Vosniadou & Brewer, 1992, 1994) interpretation of conceptual change theory emphasizes the gradual process in which knowledge structures are revised. The individual’s initial or naïve conceptions are based on intuitive beliefs and presuppositions, which can be very resistant to change depending on the degree of entrenchment within the individual’s cognitive framework. This particular focus, the lunar phases, has been researched and found to be a difficult concept to understand. The information surrounding lunar phenomena and events is more abstract than concrete for the learner. Lunar concepts are more complex than some scientific phenomena and the scientific view conflicts with everyday sensory

experiences (Sharp & Kuerbis, 2006). Because of this difficulty and the many challenges a learner confronts, concepts related to lunar phenomena may be resistant to change. Students' understandings are generally far from a robust scientific understanding about astronomical phenomena. Studies across ages and various backgrounds examined alternative conceptions related to lunar phases and the challenges learners encounter (Baxter, 1989; Bisard et al., 1994; Schoon, 1995).

The following review of the lunar research literature is organized into Descriptive and Conceptual Change Studies related to the shapes, sequence, and cause of lunar phases. Following the descriptive and conceptual change studies, a review of instructional methods and materials used in lunar intervention studies, such as inquiry in the science classroom and using technology in the science classroom, is provided.

Descriptive Studies

Conceptual understanding related to lunar phenomena has interested researchers for decades (Haupt, 1948; Kuethe, 1963). Most of the research has been descriptive (Baxter, 1989; Bisard et al., 1994; Dai & Capie, 1990). These studies catalog students' alternative conceptions and include a variety of data collection strategies such as surveys, clinical interviews, multiple-choice tests, open-ended questions, and observation.

Piaget (1929, 1972), a pioneer in conceptual change research, found when interviewing children that most held alternative, or non-scientific, conceptions about the moon's phases and the moon's apparent celestial movements. Since those early

findings, research regarding students' understanding of the moon and its phases has become more prevalent within educational communities.

Broadstock (1992) highlighted three major findings from the lunar studies, beginning with Piaget's interviews with children about the moon. Children have a firm idea about scientific knowledge before entering formal education, and many of these ideas are at variance with the scientific view. Secondly, the views held by students are persistent and defensible by the viewer. The final finding is that alternative conceptions about the moon are "consistent across ages, diverse populations, and nationalities" (p. 18).

Children's astronomical theories were explored in Baxter's (1989) study. This was an important step in helping develop material and strategies for teaching astronomy to accommodate a national science curriculum. Baxter reasoned that these astronomical phenomena, including lunar phases, are complex and "it may not be appropriate to expect understanding of such a notion (the heliocentric view) before early adolescence," (p. 511). Baxter interviewed 20 students ages nine through 16 years from southwest England. His findings guided the development of a survey instrument which was administered to 100 students.

In the interview children were asked to draw some of the moon shapes that had been observed. They were also asked if the shapes showed regularity in apparent changes. After the participants drew phases, they were asked to explain the changes using models of the Earth, sun, and moon or by drawing. Student responses varied, but the Earth's shadow being cast upon the moon was the most common understanding reported. Other notions included clouds covering part of the moon and planets casting a

shadow on the moon. Although survey results showed that there was a reduction in alternative conceptions as children matured and had more experiences, many of the naïve notions related to astronomical phenomena appeared in the oldest participants. Trumper (2001a, 2001b, 2006) reported that many of these same naïve science views continue to persist, even through adulthood.

Dai (1991) reported that fifth-grade students in Taiwan also held alternative conceptions about the moon's phases. Like Baxter's students, many of Dai's participants thought that the phases were caused by the Earth's shadow. An *eclipse* or *interference* model is described as a shadow being cast onto the moon by the Earth. In their review of the research Bailey and Slater (2003) found that some students explained the shadow as originating from a cloud or other celestial object. Dai suggested that this naïve science view might be due to the abstractness of the concept for this age child. Consistent with both Dai's and Baxter's findings, Broadstock (1992) interviewed 13 children ranging in age from 7 to 13 (Grades 1-5). Broadstock found that most of the children held the common *eclipse* conception related to the moon's phases. Five of the students thought that the Earth's shadow caused the phases. None of the children held scientific ideas about the moon's phases.

In southwestern England 42 children ages 10 and 11 were interviewed to uncover their thoughts about astronomical events and objects (Sharp, 1996). Sharp found that although all were aware of moon phases, only 40% could explain the accurate scientific causes for the moon phases. Data indicated that student knowledge varied regarding "the degree of recall over regularity, predictability and cyclic period of

the moon,” (p. 695). Most of the students were unaware of the moon’s position in the sky or its movement.

Children tend to operate on their presuppositions about their observable experiences. If an individual’s presuppositions or entrenched beliefs are thought to be successful for interpreting lunar phenomena, there will be no obvious reason for the student to change a deeply embedded conception, making conceptual change difficult (Vosniadou & Brewer, 1994). Like the younger students, older children may also rely on their personal theories based on observable experiences. These frameworks, which may be deeply rooted, may continue to interact and influence what older children believe. In a cross-age study conducted by Trumper (2001a) basic astronomy concepts held by junior high school students in Israel were analyzed. Four hundred forty-eight students in grades seven through nine (ages 13-15) were given a written questionnaire of 16 questions related to seven different astronomy topics, including the moon’s phases. In response to the specific questions, 52% answered correctly about the changes in the phases, but 19% of those students believed the Earth’s shadow caused the phases, while 25% thought the moon moved into the sun’s shadow. A number of students were confused between the cause of lunar phases and the lunar eclipse and held alternative conceptions, showing a discrepancy between what junior high school students believe and the scientific explanation for the cause of the moon’s phases.

Bisard et al. (1994) surveyed 708 students ranging from middle school to senior university levels about astronomical objects and events. The various participant groups were middle school students, high school students, freshmen and sophomore university students, junior and senior students in upper level science courses, science majors, and

general education majors with little course work in science. When asked about the cause of the moon phases, nearly 60% of the 708 students believed that the earth was involved in producing lunar phases. The accurate response rate to questions about Earth science concepts increased from middle school level to students in the advanced science classes at the university level with the exception of one group, the general elementary education students enrolled in science methods courses. General education students fell in the same conceptual knowledge range as the middle school students. According to the authors this alarming trend suggests that the general education majors, future teachers, have as many persistent, deeply rooted alternative concepts as the middle school students.

Alternative conceptions about the moon's phases and the cause of the phases are prevalent throughout the elementary, middle school and high school years. It is important for the general population to understand these concepts as a matter of scientific literacy. It is especially important that pre-service and in-service teachers are knowledgeable, since they will be expected to teach these concepts to children. In Schoon's (1995) survey of 122 pre-service elementary teachers he found that many of these participants held the same alternative concepts as the young students they may someday teach. Schoon found that 62% held the ecliptic model to be the cause of lunar phases. This was a much higher rate of inaccurate information when compared to 30% of fifth-grade students from an earlier study (Schoon. 1992).

Dai and Capie (1990) administered a multiple-choice instrument to 174 pre-service teachers from three Taiwan teacher colleges. Data indicated results similar to Schoon (1995). The researchers determined that many of the pre-service teachers held

alternative, or non-scientific, conceptions. A majority believed that the earth's shadow caused the moon's phases, while some thought the phases were caused by the amount of light being reflected from the moon.

In summary, many of the descriptive studies indicate that participants attribute the cause of lunar phases to the *eclipse* or *interference* model. This explanation, discussed earlier, is one of the most common alternative conceptions reported in the research. One shortcoming of many descriptive studies reviewed here is the method of finding evidence. Surveys and multiple-choice instruments with only a few related questions about lunar phases or cause of phases supply limited information regarding the development of conceptual understanding. Even with limited information, there appears to be a general trend in the studies reviewed which highlights a potentially significant problem. The research provides evidence that people hold alternative conceptual understanding about the cause of the moon's phases across ages, varied levels of training, and populations (Trundle et al., 2002). Describing the commonly held alternative conceptions across a diverse population is important, but research should move beyond identification of alternative conceptions into the exploration of building scientifically accurate conceptions. The next section focuses on conceptual changes in moon study research.

Conceptual Change Studies

In the review of the literature there are very few studies devoted to the effects of instructional strategies on students' understandings of the cause of moon phases (Bell &

Trundle, 2007). In most of these studies it was reported that when instruction was introduced and implemented participants' conceptual understanding of the moon's phases changed in some ways with varying degrees of success.

Osborne, Wadsworth, Black, and Meadows (1994) found in their broad primary space project investigation that 50% of the children ages 5-11 were aware of at least three lunar phases, but only 20% of the older students (Lower and Upper Juniors 8-11 years) and none of the younger (Infants 5-7 years) were able to put the lunar phases in order after an intervention period. Two intervention suggestions for teacher-instruction regarding the moon portion of the project included modeling the movement of the moon in relationship to other astronomical objects using representative shapes of the Earth, sun and moon and encouraging students to look at the night sky and make regular observations of the moon and record those observations. Only one question in this study explored children's awareness of the moon's phases after one month of observations.

In their study of fourteen advanced Grade 5 students' understanding of moon phases and eclipses, Barnett and Morran (2002) identified the students' initial incomplete or confused understandings of both phases and eclipses. This moon study, which was embedded in a larger Earth study, took place during nine class sessions. Students, during the pre-interview, were able to state different phases, but struggled to explain the cause of the phases. In the study 42.8% held incomplete or fragmented understandings of the cause and position of the moon relative to the sun and Earth. The majority, 57.1%, could not articulate their thinking prior to the instructional intervention. Using an eclectic instructional approach consisting of discussion, whole

and small group activities based on the Challenger Center's space science curriculum, individual work, and computer model programs, the authors found increased understanding in some of the students with 35.7% holding complete understanding and 28.5% having partial understanding at the conclusion of the study, while 35.7% still had difficulty developing a conceptual understanding. Barnett and Morran attributed these changes in conceptual knowledge to children's active engagement in meaningful activities. In this way children were able to become aware of their own and others' understandings. Rather than traditional science instruction with the goal of producing a correct scientific understanding, the researchers pursued a more constructivist perspective that encouraged the students to discuss, reflect their evolving conceptions in a supportive environment.

Stahly and her colleagues (1999) examined 21 third-grade students' understanding of lunar phases. Four of the students were selected to be key informants. In this qualitative study Stahly et al. included interviews prior to and after the interventions, drawings, 3-dimensional models accompanying both written and verbal responses, a written survey and six instructional activities that were from a science textbook. Students' preinstructional conceptions about lunar phases were different than the accepted scientific view, but contained some accurate aspects. All four students at the conclusion of the study had adopted some of the new scientific information to explain their understandings. For example one student's pre-instructional idea included cloud coverage as the cause of the phases, but by the end of the study he explained that phases were caused by the moon's revolution around the Earth and the Earth's position relative to the sun and moon. In fact all four students' conceptions had changed in

some way following the interventions. However, all of the students retained some of their original concepts. Even though repeated instructional activities may have supported some students' understandings, many of the original concepts lingered and were resilient to change. Like Barnett and Morran (2002), Stahly et al. (1999) found that even though there were positive changes in the students' understandings of lunar phases and eclipses, at the conclusion of the study three of the four key informants still held non-scientific views, including: scientific fragments, of the cause of lunar phases and eclipses. The authors attributed part of the difficulty to the sole use of textbooks in which facts and two-dimensional illustrations were the instructional basis rather than being actively involved in constructing their understandings. Students did not actively engage in lunar observations or lunar data collection and analysis.

In Dai's (1991) experimental-design study of 164 fifth grade students it was found that 21.4% of the participants in the experimental treatment group and 22.9% of the control group participants held a scientific view of the lunar phase concept on the pretest instrument. At the conclusion of the intervention period a majority or 64.2% in the treatment group held scientific conceptual understandings, compared to 36.1% of the control group. The experimental treatment group received the author-designed curriculum, including the field observations of the moon and dramatic play. Field observations consisted of observing the moon for a two week period and recording the lunar phases each day for three days. During the dramatic play the students would "wear" the light (sun), or the big ball (Earth), or carry the small ball (moon) so that each could experience the various perspectives in space and the relative positions of the Earth, moon, and sun. The control group used the standard textbook plan. "More

experimental students changed their misconception from the lunar phase being caused by the shadow of the earth to the accurate conception that we look at the moon from different angles” (p.99). The study lasted 200 minutes, consisting of five classes.

Targan (1988) also used a pretest posttest control group design to study conceptual change in non-science college astronomy students. A coding system to identify the content, correctness, consistency, and completeness of responses was created to measure the conceptual understanding of students during and after an instructional intervention. For Targan the scientific model needed to have all of the elements including:

1. The moon revolves around the Earth
2. The half of the moon facing the sun is always illuminated
3. When we see different phases, it is because we are seeing different portions of the illuminated half of the moon
4. The part we see is determined by the relative positions of the Earth, moon, and sun (p.84).

Fragments are responses that do not include the key elements of the correct model, but include some correct facts about the phases. “Students who appear to have no knowledge whatsoever were placed in the *no model* group” (p.88). The intervention required students to observe the moon daily for one month, order the phases from the observational data, and develop a model to explain the phases. During class, students were directly taught the phases, given 2-D drawings, and fact sheets about the phases and the positions of the moon with relation to the sun and Earth. Targan found that on a pretest 21.3% of the students held *scientific fragments of correct models*, while the majority, 60.7% held *no model* when asked information about the moon. On the posttest however, 18% held a scientifically accurate understanding or *correct model*, and the

majority held fragments of the correct model. Only 4% did not demonstrate any understanding.

Like Targan (1988), Callison (1993) found conceptual changes her study of 76 preservice elementary teachers after an instructional period. A pretest to determine prior knowledge concerning the phases of the moon was given before the interventions; randomly selected participants were interviewed prior to the intervention and again at the conclusion of the study. A posttest was given after the treatment, followed by a retention test two weeks after the posttest. The interventions included lunar observations and data collection for one month before the intervention. Additionally, four treatment groups were developed for a specific level of abstraction, each receiving a different type of instruction with the fourth group (control) receiving reading material. One treatment used role playing to answer questions, another used manipulatives, while the third treatment used 2-dimensional diagrams to explain lunar phases. All were given a fact document to read about the moon, sun, and Earth.

Responses on all of the assessments were coded in the same fashion as Targan (1988), i.e. correct model, alternative models, fragments, and no model. Of the 76 pre-service elementary teachers 51.3% held no model prior to the instructional treatments, while 6.6% held the correct model. More held fragments (48.7%) on the posttest. The manipulatives treatment group, using the psychomotor model with the light and Styrofoam ball, indicated a significant change with 64.2% holding no model before instruction to the majority (57.1%) holding alternative models after the instruction.

In the research there are very few conceptual change studies with young children, in grades three through five, as participants (Barnett & Morran, 2002; Dai,

1991; Osborne et al., 1994; Stahly et al., 1999). The four studies had significant limitations. Osborne et al. (1994) developed multiple intervention activities from which teachers could select. The teachers were encouraged to use at least one activity from each section of the broad study, but there was no attempt to ensure consistency within the study. Barnett and Morran used a small, unique sample of 14 academically advanced grade five students. An eclectic instructional approach directed toward accommodating different learning styles, was utilized with this atypical sample. The scenario was atypical, as well. The selected students were taking a special science course, and would ultimately visit a Challenger Center to simulate a NASA mission. The setting seemed highly motivational and less conventional than most science classrooms.

Stahly et al. (1999) had a small number of grade three students, as well, with four key respondents participating. The children were presented with six textbook lessons, which included some drawing and the use of models. Textbooks are commonly used in the United States in elementary science classrooms (Appleton, 2007). When using this form of instructional material, students rely more on text reading and less on hands-on inquiry learning. Typically science content in a textbook is conveyed through written text with a “heavy emphases on vocabulary learning and factual recall” (p. 502). Didactic models of teaching lunar content knowledge may promote the development of some information, but this new information may not be transferable to new situations. Knowledge acquired through simple memorization is frequently forgotten and not incorporated into a conceptual framework. This model of delivering knowledge to students does little to correct alternative concepts children and adults hold in science

(Wandersee et al., 1994). The use of printed material as the primary instructional strategy was noted by the authors as a limitation of their study.

Neither Stahly et al. (1999) nor Barnett and Morran (2002) used lunar observation or data collection to help children grapple with their alternative conceptions of phases and the cause of phases. Active involvement in collecting and analyzing lunar data of the phases may have helped the students view possible contradictions between their personal understanding and the scientifically accurate perspective. Peer discussions during the data analysis phase in a collaborative setting often motivates others to consider new or conflicting information (Mason, 2001).

In summary, the review of the conceptual change literature on children's understanding of the moon phases and the cause of the phases, which is the focus of this study, is limited. This is an educational research area that needs to be explored further. Only one study (Trundle et al., 2007a), has thoroughly investigated student learning in a specifically designed instructional environment. Trundle's et al. study included inquiry-based pedagogy relative to the *National Science Education Standards* and reported significant results with young children. More student-centered and inquiry-based instructional approaches, like the Trundle et al. study, offer encouragement for science educators.

Trundle and her colleagues (2002) identified lunar phenomena instruction that was effective with pre-service elementary teachers' understanding of the causes of lunar phases. In determining whether "moon-related content identified in the *National Science Education Standards* for the K-4 level can be taught successfully" (2007a, p. 597) Trundle et al. used a similar instructional intervention with young children. The

authors designed a standards-based (Earth and Space K-4) and inquiry-based study in which young students' understandings of lunar phases, sequence and patterns of lunar phases, and cause of lunar phases significantly changed. The qualitative study with 48 grade four students lasted nine weeks. The instruction was based on *Physics by Inquiry* (McDermott, 1996). The study, which utilized multiple representations of student learning modes, reported that young children were able to collect, record, and share observed moon data; analyze and predict lunar patterns and sequences; complete instructional activities; and explain, while using 3-dimensional models in a psychomotor activity, the causes of lunar phases within a guided inquiry setting. Children's drawings of observable moon shapes and the sequence of lunar phases were used as pretest and posttest data. Ten of the students were selected and interviewed at the end of the intervention to provide data related to student knowledge about the cause of lunar phases. During the interviews students used 3-dimensional models to demonstrate their thinking, while explaining the cause of moon phases.

For nine weeks the students collected observable daily moon data in small groups, recorded the data on a moon calendar, and shared their findings weekly within a whole group setting. At the end of this time, students, working collaboratively in small groups, were directed to look for the eight observable lunar patterns (shapes) and sequence of changes (order of shapes) within their data collection.

A psychomotor activity modeled after McDermott (1996) was devised to engage the students in an active learning episode. The children manipulated a Styrofoam ball (moon) at arm's length and revolved it around themselves (Earth perspective) while standing in front of an illuminated light bulb (sun). As the Styrofoam ball was moved

in quarter turns around the individual, a different phase or lighted portion was noted by many of the students. This simple observation led to changes in student ability to accurately draw lunar shapes. Knowledge of observable lunar shapes represented in student drawings changed from 50% preceding intervention to 93.4% after intervention. Similar positive results were found for knowledge of lunar phase sequences. Pretest results indicated that 36% were able to draw scientifically correct waning sequence, while 16.1% of the participants were able to represent the waxing sequence accurately. After intervention, the percentage of accurate responses increased: (a) all of the children generated a predictable sequence in moon phases, (b) 62.5% correctly represented the waning sequence, and (c) 70% of the waxing sequence drawings were judged to be scientifically accurate.

Knowledge of the existence and sequence of lunar phases is listed in the NSES for K-4 grade band. However, the cause of the lunar phases is not considered appropriate for this age level. Trundle et al. (2007a) suggested that research was needed to determine whether moon-related content outlined by the NSES for K-4 level could be taught using effectively designed instruction. In previous research Trundle et al. (2002) found an effective instructional strategy that supported preservice teachers ability to describe moon phases and sequence of change in lunar patterns. This same instruction was used in the fourth-grade study.

The Trundle et al. study did not intend to include results related to cause of moon phases, but children appeared to be going beyond the focus of the study. A sample subgroup was formed to pursue further information. In the posttest sub sample interviews 8 of the 10 students demonstrated complete scientific explanation of the

cause of moon phases. The remaining two students held scientific fragments with no evidence of an alternative concept to explain the cause of moon phases. “These results do not support the view that developing an understanding of the cause of moon phases is more conceptually demanding or less appropriate for Fourth-grade student than observing, describing, and drawing phases and patterns in moon phases” (p.611). The participants went beyond academic expectations and spontaneously began inquiring and predicting the cause of the lunar phases.

Metz (2004) would contend that this type of inquiry was scaffolded initially through whole group explorations of lunar observations and sharing of the data. This type of authentic inquiry without decomposition of the processes allowed children to effectively take responsibility and control for understanding these science phenomena, while developing their capacity to become independent inquirers. Metz suggested that the NRC (1996) parsed (or decomposed) into components the process skills related to doing full inquiry, especially at the Grade K-4 level. This can be problematic for children when the “form of scientific inquiry is at any grade level [is] restricted to the subset of processes purportedly within the repertoire of children at that point in their cognitive development” (p. 221).

The ways learners make sense of their world and construct knowledge are important factors in developing and improving science education. Many of the studies reported in this review have identified commonly held non-scientific conceptions. Bailey and Slater (2003) summarized and categorized the literature on astronomy education research of both quantitative and qualitative studies. They suggested that more work is needed to uncover not only the underlying causes of student difficulties

with the various astronomy phenomena, but also effective instructional strategies to help children learn (Mulholland & Ginns, 2007).

As Parker and Heywood (1998) suggested, the research paradigm needs to move beyond identifying the concepts students hold toward key features of the learning process and how these features can be more effectively supported. More research is needed to determine if the lunar phase content in the *National Science Education Standards*, including observing, describing observations and finding lunar patterns that is expected by K-4 students is appropriate. Also, more research is required to determine effective instructional interventions that will support young students' understanding of lunar concepts.

Science Inquiry

More recently there has been a shift in the way science education is viewed. Today the focus in science classrooms includes direct experiences with authentic, inquiry-oriented, activity-based contexts. The *National Science Education Standards* (National Research Council, 1996) calls for inquiry as the central strategy in science education and defines it in this way:

Inquiry refers to diverse ways in which scientists study the natural world and propose explanations based on the evidence...It refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (NRC, 1996, p.2).

“...engaging students in inquiry helps students develop...an appreciation for ‘how we know’ what we know in science, understanding of the nature of science and skills necessary to become independent inquirers about the natural world” (NRC, 1996, p. 105).

Inquiry has been a persistent theme in science education for some time, but the meaning of the term varies depending upon the context in which it is placed. The *National Science Education Standards* (NRC, 1996), which documents quality science instruction, refers to three categories of inquiry: scientific inquiry, inquiry in learning, and inquiry teaching. *Scientific inquiry* refers to the ways in which scientists investigate our natural world. Using investigative skills, like observing, inferring, posing questions, forming an hypothesis, testing the hypothesis, and finding some conclusion based on their analysis of the data is similar to the work of a scientist. *Inquiry learning* implies an active process of constructing meaning in the science classroom. According to Anderson (2007), *inquiry learning*, like constructivist learning, suggests that:

1. Learning is an active process of individuals constructing meaning for themselves; significant understanding are not just received.
2. The meanings each individual constructs are dependent upon the prior conceptions this individual already has. In the process, these prior conceptions may be modified.
3. The understandings each individual develops are dependent upon the contexts in which these meanings are engaged. The more abundant and varied these contexts are, the richer are the understandings.
4. Acquired meanings are socially constructed; understanding is enriched by engagement of ideas in concert with other people, (p. 809).

Combining both *scientific inquiry* (investigative processes) and *inquiry learning* would be a focus in an inquiry-based science classroom. The expectations for using *inquiry teaching* as identified in the standards (NSES) is less clear, because of its abundant forms.

Many levels of the inquiry exist. Martin-Hansen (2002) suggested there is a continuum of inquiry types in the literature which includes open or full inquiry, guided

inquiry, coupled inquiry and structured inquiry. These inquiry strategies range from an open-ended exploration or student-centered to a more teacher-directed or text-directed exploration (Barman, 2002; Martin-Hansen, 2002). Martin-Hansen described open inquiry as an approach that has students working directly with the equipment and concepts, while designing an investigation, similar to the work of scientists.

Literature supports the fact that children have weak areas when working on independent science inquiry processes. For example, young children have difficulty designing experiments that show clear conclusions, the evidence gathered may not even support the purpose of the experiment, and they aren't particularly troubled by it (Dunbar & Klahr, 1989). In that same summary, Dunbar and Klahr found that children appear to have a basic understanding of what steps the scientist needs to follow, like observing and arriving at a summary statement of the findings.

One interpretation in the literature, according to Sodian, Zaitchek, and Carey (1991) is that "young children have limited metaconceptual understanding of notions like *hypothesis* and *test*" (p. 753). Although children begin to understand the differences between beliefs and reality and understand that beliefs may or may not be true, it is not until about age 6 that children "possess the conceptual prerequisites for understanding how evidence bears on hypothesis" (p. 755). It is about this age that young children begin to generate inferences about phenomena.

In the standards there is what Metz calls a "decomposition of scientific inquiry" (2004, p. 221). In the Grade K-4 standards students are asked to make observations, use tools, sort objects, and describe phenomena. The standards state that young children "have difficulty with experimentation as a process of testing ideas," (NRC, p. 121).

According to Metz, “there is considerable evidence that decomposition and decontextualization of the scientific process are not necessary to keep within the ‘developmental constraints’ of the elementary school children’s capabilities” (p. 222). Metz suggests that young children can build their capacity to become independent inquirers through scaffolded engagement within a collaborative environment in science classroom, such as reported by Trundle et al. (2007a).

Scaffolding children’s engagement by using whole group and small group instructional interventions and materials can effectively support young children’s inquiry within the science classroom. Collaborative cognition, working within a community, can significantly reduce the cognitive work for the individual. Much like scientists, children can share tasks, enabling complex intellectual work to be managed more effectively (Metz, 1998).

Despite the call for inquiry highlighted in the NSES and the positive aspects of children’s engagement with inquiry, there is very little empirical research surrounding the use of inquiry with young children in the science classroom. This study collected lunar data and use inquiry to pose questions, observe, explore sequences, make and check predictions, much like the work of scientists.

Technology-rich Environment

Although students cannot visit the moon to learn firsthand about lunar concepts, they can manipulate environments, set times to watch moonrise and moonset, and track the moon’s dynamics easily by using planetarium software. In this way science educators can create a virtual reality for their students set within a constructivist frame

for learning about the moon's phases and celestial movements. Software can serve as a vehicle for posing questions, collecting data, predicting and checking assertions, and analyzing collected data, related to lunar phases.

Songer (2007) suggested that using technology to support scientific inquiry is an effective way to gather, analyze, and interpret data. Technology also allows the user to explore and manipulate environments and objects in order to develop an understanding of abstract concepts like lunar phases.

Making daily moon observations to collect lunar data over several weeks can be time consuming and frustrating for students. Depending upon the visible sky due to weather conditions and obstructions such as buildings, the collection of lunar data may be difficult, if not impossible. Planetarium software programs like *Starry Night* (version 5.0) can offer an easy solution for the classroom science tasks. *Starry Night*, the planetarium software by Imaginova, offers a rich context for scientific inquiry related to Earth Science. This software program provides a sophisticated, scientifically accurate simulation of our universe. Using this software on personal computers makes it possible to predict and check lunar understandings with flexible viewing positions and times. This software has been recommended by other educators (Trundle & Bell, 2003) as a powerful tool for experiential inquiry, because of its wide range of applications, its realistic simulated environments, and relatively simple access for the user.

The National Science Education Standards suggest that students make observations over time, collect data, look for patterns, and make predictions related to lunar information. This software allows students to do all of these things in a timely manner. Computer simulations, if designed effectively, can support learning in the

science classroom (Akpan & Andre, 2000; Bayraktar, 2002; Trundle & Bell, 2006; Yair, Mintz, & Litvak, 2001).

Previous research has demonstrated the value of computer simulations in the science classroom. In a study of 65 students, ranging in age from 13 to 15, Akpan and Andre (2000) found that students using a frog dissection computer simulation program prior to the actual dissection performed significantly better on the dissection performance test than students not using the program. Monaghan and Clement (2000) concluded that computer simulations had an effect on logical reasoning and inquiry for high school physics students working on relative motion scenarios. Students using the computer simulation (animation condition) revealed striking differences in problem solving when compared to students using numeric processes only (algorithmic calculations). The researchers found that students using the simulation displayed evidence for developing mental models of motion to make predictions and test predictions, related to the physics problem.

Keating, Barnett, Barab, and Hay (2002) reported that students using a computer model-building program demonstrated considerable gains in their conceptual understanding of the moon phases and the cause of phases and eclipses. Students were able to visualize the abstract concepts related to the position of the Earth, moon, and sun by developing 3-dimensional models and by changing their frame of reference and viewing perspectives. The computer simulation program also allowed them to create, manipulate, and interact with the models.

Bell and Trundle (2008) reported significant gains in achievement when pre-service teachers used a technology-enhanced inquiry instruction. Pre-service teachers

using only *Starry Night*, a computer simulation program, to make lunar observations over a nine-week period demonstrated considerable gains in conceptual understanding of lunar concepts, compared to pre-service teachers using natural observation and a combination of natural observation and the computer simulation program to collect lunar data. Although all three groups reported gains from preinstruction to postinstruction, the *Starry Night* group reported the highest gains on the four targeted moon phase conceptions.

In summary, the research supports the use of effectively designed computer simulations in the science classroom to extend and develop understanding of this science domain. Computer simulations have been found to support logical reasoning and problem solving (Monaghan & Clement, 2000). Students using computer simulations demonstrated evidence of developing mental models to test predictions. In other studies computer simulations supported students' ability to visualize abstract concepts (Akpan & Andre, 2000; Keating et al., 2002) by manipulating models.

Using planetarium software is one way students can observe regularly occurring astronomical phenomena without leaving their environment. Conducting natural data collection is not always possible. For example, students may not be able to observe daily phases of the moon due to the weather conditions or physical obstructions within their environment. Gathering multiple data may be impossible due to time limitations on the student. Planetarium software frees the student to gather data regardless of the weather or time of day (Bell & Trundle, 2008). Students can access real time data related to moonrise, set, lunar movement and direction, and orientation with very little effort.

Conclusion

Children come to the science classroom with personal knowledge that may be based on multiple experiences with the physical world. This knowledge may be at variance with scientifically accurate knowledge and may be robust and resistant to change.

A review of the descriptive studies related to lunar phase research catalogs students' conceptions across ages and backgrounds. This body of research demonstrated that, although student responses varied, the most common alternative conception related to the cause of the moon's phases was the eclipse or interference model. This model explains that the Earth or other astronomical bodies casts a shadow or interferes with the full view of the moon (Baxter, 1989; Broadstock, 1992; Dai, 1991; Trumper, 2001a).

Although students cannot visit outer space for a clearer astronomical perspective, development of lunar concepts can occur from multiple and effective experiences with lunar concepts. In the literature exploring conceptual change researchers moved beyond identification of commonly held alternative conceptions to the effects of instructional interventions on student knowledge in this domain. Specifically, in a review of the research related to lunar phases evidence of change with varying degrees of success in student understanding is documented. For example, Barnett and Morran (2002) found that after implementing an eclectic instructional intervention there was change in student understanding in Grade 5 students with 35.7% of the fourteen students holding a complete scientific understanding of the cause of

moon phases, while 28.5% held a partial understanding. Similarly, Stahly et al. (1999) reported changes in student understanding after implementing an intervention. Even though there was evidence of change, three of the four informants held non-scientific understandings of the cause of the moon phases and eclipse

Trundle et al. (2007a) reported significantly positive changes in students' understanding of lunar phases. In this study the Grade 4 students worked collaboratively to gather, record, and analyze moon phase data, as well as participate in inquiry-based and standards-based activities based on *Physics by Inquiry* (McDermott, 1996). In this study students demonstrated significant changes in their understanding of lunar knowledge. For example, prior to intervention 36% of the participants were able to draw scientifically correct waning lunar phase sequence, while 16% of the participants were able to represent the waxing phase sequence. After the intervention period, the percentage of accurate responses increased to 62.7% and 70% respectively. In a post-intervention interview 8 of the ten participants demonstrated complete scientific understanding of the cause of moon phases. This finding is particularly significant for the present study. According to the policy documents the *National Science Education Standards* (NRC, 1996) and the *Benchmarks for Science Literacy* (AAAS, 1993), this task is conceptually demanding and an inappropriate expectation for Fourth-grade students. These students went beyond the expectations that guide our science teaching. "These results do not support the view that developing an understanding of the cause of moon phases is more conceptually demanding or less appropriate for Fourth-grade students than observing, describing, and drawing phases and patterns in moon phases" (Trundle, et al., 2007a, p. 611).

The essential argument for the present study is that the NSES expectations may not be appropriate for Grade 2 or 3 students, based on the Trundle, et al. findings. These findings suggest that children need to be actively involved in the construction of knowledge within a targeted domain, moon phases. The intervention and the environment need to be designed to promote scientific inquiry in a collaborative setting and based on the constructivist pedagogy that values children's initial ideas as an important aspect in the process of change.

Inquiry refers to the various ways in which scientists study our natural world. Students can develop an appreciation for how science knowledge develops with authentic tasks that include using investigative skills like observing, inferring, asking questions, forming and checking hypotheses, and drawing conclusions from the findings. The present study included authentic science inquiry and data collection related to observable moon phases. Many levels of inquiry exist (Martin-Hasen, 2002) ranging from open, unstructured inquiry to teacher- or text-directed inquiry. Metz (2004) suggests that there is considerable evidence that young children can build their capacity to become independent inquirers through scaffolded engagement within a collaborative environment, such as the one Trundle, et al. described. In the current study children's engagement was supported by using whole group and small group instructional interventions, as well as supportive materials.

Inquiry-based and technology-enhanced instruction has been demonstrated to allow students access to challenge their thinking and explore the moon without leaving the science classroom. Computer simulation programs have appeared to provide

opportunities for science students to collect moon data easily and in a timely manner (Trundle & Bell, 2003).

Vosniadou's (e.g., Vosniadou, 1991, 2003) conceptual change model was used as a framework for the present study. Learning to Vosniadou requires time and opportunities to interact with science phenomena and with others within the science context. Early knowledge about the world helps children form naïve theories that are used to formulate explanations and predictions related to everyday phenomena. Children establish mental models to reconcile their previous assumptions and new information. The models help the student reflect and interpret the new information, using existing ideas. As the student explores and learns about the targeted domain, the student's existing model may change. Conflict between what the student believes to be true and the scientific understanding does not ultimately lead to conceptual change, but leads to a progression in personal alternative conceptions. As the student begins this progression toward concept resolution, he/she will need assistance to explore, check and revise his/her thinking.

Vosniadou's conceptual change model and this study align on two points. According to Vosniadou, students need to be actively involved in the construction and planning of their learning. The present study encouraged students to collect data, record, share, and analyze moon data over a period of time. During this time, students were encouraged to predict and check their predictions related to the lunar data they collected. Vosniadou also suggested that science learning does not happen in a vacuum. There are social and cultural factors that may support learning. Students

worked collaboratively within the environment. They were encouraged to share thoughts through group and peer-discussions and writing tasks. Both of the points described reflect the findings of research studies from the science education and from the cognitive psychology perspectives that were explored in this study.

CHAPTER 3

METHODOLOGY

Introduction

The purpose of this mixed methods study was to describe, report, and interpret young children's conceptions of observable phases of the moon, the regularity of moon phase sequences, and causal explanations of lunar phases before and after an instructional intervention. Children collected and analyzed lunar information using a planetarium software program, *Starry Night* (version 5.0). In addition, they participated in inquiry-based instructional activities, based on a science module *Phases of the Moon* in *Physics by Inquiry* (McDermott 1996). Although research has identified some of the mechanisms that support the construction of meaning (Vosniadou, 1991), less has been accomplished in finding effective ways to help children learn (Parker & Heywood 1998).

The paradigm needs to move from identifying the problems learners encounter and the constructs they use to interpret meaning, toward identifying key features of the learning process itself and determining their effectiveness in developing ...knowledge and understanding which is coherent with science models of explanation of basic astronomical events (p. 505).

This study was modeled after two recent research studies: *Fourth Graders' Conceptions of Lunar Concepts* (Trundle et al., 2007a) and *The Use of Computer Simulation to Promote Scientific Conceptions of Moon Phases* (Bell & Trundle, 2008).

Trundle and her colleagues used an instructional intervention with young children to promote conceptual understandings of the moon phases, while the Bell and Trundle study focused on using a computer simulation program to gather lunar data.

Since this mixed methods study focused on young children's understandings of lunar concepts, qualitative methods were used (Mason, 1996). Qualitative research methods allowed the researcher to look at multiple data samples that provided rich, contextual details of how children make meaning and interpret their experiences. These methods allowed the researcher to systematically and rigorously collect data at multiple points throughout the study for analysis. Along with collecting and analyzing qualitative data, quantitative nonparametric tests were also employed.

This chapter describes the (a) research context and participants, (b) instructional intervention (c) data collection, (d) data analysis, and (e) trustworthiness of the study.

Research Context and Participants

District

A classroom-based research project with the teacher as the researcher was conducted within a mid-sized Midwestern suburban school district. At the time the study was conducted the school district had an enrollment of 14,217 students in twenty schools with grades ranging from Kindergarten to grade twelve. The district's population included 18% minority students. Twelve percent of the total population was disabled, 6% were limited English proficient, and 15% were economically disadvantaged. More than 65% of the teachers within the district held a Masters degree at the time the research was conducted.

School

The inquiry-based, suburban elementary school where the study took place had an enrollment of 505 students in grades Early Primary (kindergarten, first-grade students) through Intermediate (fourth-, fifth-grade students). There were 269 males and 236 females attending this school. Most of the students were Caucasian (84.55%), while 6.53% were Asian, 2.18% were African American, and 2.18% were Hispanic/Latino. There were 3 American Indian students (.59%). A small percentage of the students received free or reduced lunch (8.31%), indicating a low level of poverty in the school.

The school was considered well-equipped with technology, as each classroom contained 5 or 6 computers. Students also had access to a full computer laboratory and a mobile 16 unit laptop cart. All computers had Internet connectivity.

Classroom

The context for this study was in the natural setting of a Primary classroom (Grades 2 and 3). The instructional intervention took place within one Primary classroom over the course of a six-week period, during the scheduled science time and during free work time. The participants worked individually, in small groups, and in whole group throughout the study.

The self-contained classroom was designed so that children had free access to resources. Shelves that line three walls were at a conveniently low level to encourage browsing of the displayed science projects, plants, pets, and science books. Materials and tools were on lower shelves in cupboards so that children could reach objects they

might need for projects. Nonfiction texts lined the bookshelves, specific science shelves were available for objects and curiosities children and teacher brought to share or investigate. The philosophy and attitude within this environment was one of inquiry with child-directed investigations and curriculum-inspired investigations going on throughout the day. In this self-contained classroom there were 5 computers with Internet access that the children used daily.

Students

Twenty-two Primary children (12 boys and 10 girls) from a self-contained multiage classroom participated in this research study initially. One student was excluded from the data set due to an extended absence from school. At the conclusion of the study twenty-one students were included in the data set. This class contained children in second and third grades. The ages within this heterogeneous class ranged from 7 to 9 years. Seven students were identified as cognitively gifted, while three received special support services. This age level of participants was selected based on the *National Science Education Standards* (NRC, 1996) which state that understanding lunar phenomena is part of the curriculum included in the K-4 Earth and Space standard. As stated in the standards, children were expected to observe lunar patterns and movement of the moon over a period of time. Nine children were students in this classroom last year in which a physical science unit *Light* was explored. Some topics that were investigated at that time included: the sun, light rays, reflection, and shadows.

Research Team Members

Members of the research team include the principal investigator, who is the classroom teacher and teacher-researcher, and two trained interviewers.

The participant observer led the instructional activities and collected and analyzed data in the classroom. She videotaped, audio-taped, and transcribed classroom activities and recorded field notes and memos, noting locations of people, materials and their interactions.

The participant observer had prior experiences, both as a student during doctoral coursework and as a teacher in a professional development institute, where the materials and the instructional activities used in this study were introduced. The participant observer also had more than 25 years of teaching experience. The sum of these experiences along with pedagogical knowledge developed during master's studies provided skills and knowledge to implement the instructional intervention. Courses taken at The Ohio State University provided an opportunity for the investigator to plan and execute the research project.

The trained interviewers included a science education professor at a large mid-western research university and an early childhood science education doctoral student. Both members had considerable experience conducting interviews with various age groups. The trained interviewers interviewed students individually, using six tasks that are outlined in the data collection section. The interviewers had previously conducted lunar phase interviews, which followed the protocol used in this study, with elementary and middle school students and pre-service and in-service teachers (Bell & Trundle, 2008; Trundle, et al., 2002, 2007a, 2007b).

Instructional Intervention

The instructional interventions discussed in this section included both lunar data gathering and analysis activities, using the *Starry Night* (version 5.0) planetarium software, and the inquiry-based instruction on moon phases published in *Physics by Inquiry* (McDermott, 1996). In this initial phase of the study the participants were instructed how to use *Starry Night* in order to gather and record moon data. The planetarium software allowed the students to collect lunar data in a timely, practical manner. Using this technology collaboratively, the students were able to gather nine weeks of lunar data during five weeks of classroom time. One week of observational lunar data was collected during the first week of instruction. For the next four weeks of instructional time, two weeks worth of observational lunar data were collected each week. At the end of the lunar data gathering period the participants had collected nine weeks, or two lunar cycles, of moon data. The instruction was based on *Physics by Inquiry* (McDermott 1996) and consisted of three parts: (1) gathering, recording, and sharing lunar information, (2) analyzing the data and looking for patterns, and (3) modeling the Earth-sun-moon relationship. The instructional intervention has been used by other researchers, who found it to be effective (Bell & Trundle, 2008; Trundle, et al., 2002, 2007a, 2007b; Trundle & Bell, 2006).

Gathering and Recording Lunar Observations

A planetarium software program, *Starry Night* (version 5.0) was introduced at the beginning of the first week of gathering moon observations. The participant observer demonstrated the flexibility of using the program and some of its features, including setting the date, time, observation location, and orienting the viewer to

cardinal directions. Next, the participant observer demonstrated how to collect and record the moon data. Children were asked to arrange themselves into small working groups of three to five participants for the remainder of the study. The groups needed to represent both genders and levels of experience, including older and younger students (Rogoff, 1995). The first week of moon observations, moon data recording and sharing took place. More experienced elders assisted novices initially with navigating the software, recording the lunar data and sharing their lunar data. The rest of the lunar information was collected using *Starry Night*. This information was shared daily between members of the group and recorded on the moon calendar.

The participant observer modeled how to record the daily lunar observations. Each participant had a moon calendar in which he/she recorded daily information. The calendar had a circle in each daily block. See Appendix A for the Moon Calendars. This circle was filled in according to the observed illumination for that day. Under each circle were three lines to record date, time, and the direction the moon appeared in the sky at the time of the observation. The lunar data was recorded on a large laminated community calendar that was posted in the room.

The amount of observable lunar data collected provided students with two full lunar cycles. This extensive collection of data was recommended by the *Physics by Inquiry* curriculum and was consistent with previous research on interventions that promote scientific understanding (Trundle, et al., 2002, 2007a, b). This rich data source allowed students many opportunities to make and check predictions, pose questions, and form conclusions about lunar changes. The software made data collection relatively easy for the students. The moon observation data were gathered,

recorded, and shared within small and whole group settings at the end of each week. Anomalies were checked easily and efficiently, using *Starry Night* time set feature.

There was one moon calendar prominently displayed on the wall of the classroom that was updated by a self-appointed student daily and included date, time of observation, direction that the moon appears in the sky, and the moon disc illumination shaded in the circle.

At the end of each week the whole group met and shared information related to the moon data. The participant observer facilitated weekly data sharing and discussion. In case of disputed information, the participants referred to *Starry Night* for data clarification. This information was added or amended in personal moon calendars. Children were prompted by the participant observer to respond and reflect on the week's data and then write in their journals. Prompts included, for example, "*What did you notice about the shape of the moon this week? Does the appearance of the moon's shape vary from day to day? If it changes, does the change occur gradually or does it happen quickly?*"

Analyzing the Lunar Data

At the end of the five-week lunar data-collecting period, children worked with their groups to analyze lunar data and look for any patterns and share with the whole group. There were five tasks that were completed during that week.

Students analyzed data by looking for patterns and then modeling moon phases. The key aspects of analysis included:

- identifying shapes and patterns of the moon
- finding the length of one complete lunar cycle

- sequencing the observed lunar shapes
- applying new concepts and scientific labels to the lunar shapes
- modeling the cause of moon phases.

See Table 3.1 for an overview of the instruction. Also see Appendix B for the Student Moon Journal, which includes the prompts to guide students' inquiry.

Targeted Concepts	Summary of Activities
Shapes and patterns of moon phases	1. Identify and describe patterns. 2. Describe rate of change (i.e., gradual or abrupt). 3. Draw an observed sequence of moon shapes. 4. Identify when the sky was clear but the moon could not be observed.
Length of the lunar cycle	1. Number data from day 1 to day 63. 2. Select a distinctive shape, and list the number of the day that the shape first appeared and list the number of the second and third days when the shape reappeared. 3. Repeat with 3 additional shapes. 4. Estimate how much time passed before each shape reappeared.
Sequence of moon phases	1. Sequence a series of drawings of 8 representative phases in the pattern observed.
New concepts and scientific labels	1. Use the scientific term “new moon” to describe when the moon could not be observed during the moon cycle. 2. Use the scientific term “synodic period” to describe the time interval from new moon to full moon and back to new moon. 3. Apply scientific labels (e.g., waxing gibbous) to each shape.
Cause of moon phases (Psychomotor modeling activity)	1. Place a bright, exposed light bulb at eye level to represent the sun in a darkened room. 2. Use a Styrofoam ball as a model for the moon. 3. Hold the ball in front of body at arm’s length. 4. The student’s head is the earth, move the ball around their heads. 5. Note the appearance of the lit portion of the ball and determine how much of the moon is lit at any one time 6. Use the models to reproduce all the phases in the order they were observed. 7. Write and orally explain their understandings of the causes of moon phases.

Table 3.1 *Summary of Instructional Activities* Trundle, Atwood, Christopher, & Sackes (in review) *Learning and Instruction*.

Task A: Patterns.

To identify observable lunar shapes, the groups analyzed their data and looked for patterns, using the completed moon calendars and Task A in their moon journal. As children began to analyze their moon data, they were encouraged to look for patterns, predict future moon shapes, and check data to confirm or disprove their predictions. Oral prompts that were included were, *“Look at your moon data. Is there any repeating pattern to the shape of the moon? Describe that pattern. Does the moon change quickly from one shape to the next or does it change gradually? What do you notice about the shape of the moon? Were there days when the moon was not visible?”*

Task B: Length of the lunar cycle.

In order to determine the length on one lunar cycle, the students completed Task B in their moon journals. Students numbered the days of their moon observation consecutively. The first day was numbered “1”. The next day was numbered “2”. Each day after that was numbered sequentially, including all of the data. As a group, students chose a day on which the moon had a distinctive shape, and recorded that shape on the chart in the moon journal. As carefully as possible, the students estimated the days on which the same shape occurred and recorded the “day” number on the same chart. Children were asked to find the difference between the day numbers when the moon’s shape reoccurs. The students chose another shape and repeated the process of determining the number of days in a complete cycle. This process was done with other distinctive shapes, until the participants were satisfied that the approximate time of a cycle is 30 days. If an oral prompt was needed, the participant observer asked *“Is*

there about the same number of days between observations of a [full moon]? How much time passes before the shape reappears? This period was named *synodic period*, the term used by scientists.

Task C: Sequencing shapes.

Each working group was given a copy of eight representative moon shapes that were copied from *Physics by Inquiry*. The children, while using their moon calendars, were asked to arrange the phases in the sequence that they observed them occurring during the data collection period. After sharing and discussing the sequence, the shapes were cut apart and glued or taped in their moon journal for Task C.

Task D: New concepts and scientific labels.

The participant observer encouraged the children to analyze their moon calendars and talk about their data and share anomalies. The *new moon* came up in their discussion. The participant observer asked about days when the moon was not visible and explained that this is considered the beginning of a cycle. This moon phase was labeled the *new moon*. Next, the participant observer asked the children if they noticed the moon's shape, its illumination, appearing to grow, after the new moon period. Those phases were labeled the *waxing* moon series. The moon's phases that appeared to be shrinking in area of illumination were labeled the *waning moon* series. Finally, the participant observer facilitated a discussion about the common eight moon phases that are seen during the synodic period: waxing crescent, first quarter, waxing gibbous, full moon, waning gibbous, third quarter, waning crescent, and the new moon. Up to this point the students have used their own language to describe the moon phases. The participant observer scaffolded children's learning by giving the students the

scientific labels of moon phases. At this point the participant observer provided larger versions (8x11in.) posters of each of the eight lunar phases to post after children painted the illuminated portion on each poster. Students created a glossary of definitions in their moon journal for Task D. The students applied the scientific labels from Task D to the sequence developed in Task C and wrote the labels. The children also wrote scientific labels for each of the painted poster-sized moon phases.

Task E: Modeling moon phases (Psychomotor modeling activity).

Following the activities related to lunar shapes and the sequence of the shapes, students participated in a psychomotor modeling activity. This activity was designed to promote a scientific understanding of the cause of the moon phases, using a three-dimensional environment. One child from each working group began the task. Children took turns modeling, while the others coached or observed. In a darkened room there was one exposed, lighted bulb at eye level. The bulb represented the sun, a Styrofoam ball on a pencil represented the moon, and the participant represented our Earth perspective.

The participant observer demonstrated the activity initially. The participant observer held the Styrofoam ball (moon) extended from her body (earth) toward the bulb (sun) and turned her body counterclockwise in one full revolution. Then children attempted the task. Each child had an opportunity to extend the Styrofoam ball (moon) at arm's length slightly above their head (earth perspective) and toward the bulb (sun). As each child revolved counterclockwise with the Styrofoam ball extended, he/she was asked to notice the lighted portion of the ball. Oral prompts included: "*How much of the moon is lit at any one time?*" The participant observer prompted a discussion of the

students by saying “*Stop the movement of the moon (ball) in front, what part of the moon (ball) is illuminated (lighted)? As you turn the moon (ball) counterclockwise, what part of the moon (ball) is illuminated? Are you noticing any changes in the illuminated portion of the moon (ball)? You (earth) have made a half turn. Are you noticing any changes in the moon’s appearance? Continue moving slowly counterclockwise. What do you notice about the moon’s (ball) appearance? Go back to the starting position with the moon (ball) extended in front of you toward the sun (bulb) What do you notice?*” If a prompt was needed to cue the student’s visual attention to the moon’s phase, the participant observer asked what they notice about the lighted portion of the ball at different points. The children were encouraged to complete the moon’s revolution several times, noting the lighted portion. The participant observer prompted engagement by asking “*Can you reproduce all of the eight representative moon phases in the correct order using the ball and light bulb? How is this like the moon phases that we observed and recorded?*” Students were asked to complete Task E writing in their moon journal after the activity and discussion. This writing reflected the child’s thoughts, questions, and observations made during the task.

Data Collection

The data for this study were collected using the interview responses, classroom observations, videotapes and audio-tapes of the activities, and the children’s moon journal. All of these sources were used to provide rich, detailed information about the participants’ conceptions of moon phases.

Interviews

The focus of the study suggested that the participant's knowledge, views, and understandings of lunar concepts are worth exploring with an in-depth interview. The structured, semi-formal interview (Glesne, 1999) were conducted by trained interviewers both before and after the instructional intervention in order to provide rich, detailed information about the student's understandings of lunar phases, lunar sequences, and the cause of lunar phases. The interview tasks were based on the key concepts identified within the *National Science Education Standards* (NRC, 1996) as well as previous research (Trundle et al., 2002, 2007a, 2007b; Trundle & Bell, 2006). These interviews consisted of six tasks. According to Sharp (1996) researchers often use modified clinical interview procedures, typical of Piagetian form, when investigating science related phenomena. Piaget (1929) stated:

The good experimenter must, in fact, unite two often incompatible qualities, he must know how to observe, that is to say, to let the child talk freely, without ever checking or side-tracking his utterance, and at the same time he must be constantly alert for something definitive, at every moment he must have some working hypothesis, some theory, true or false, with which to check (p. 9).

The responses given by the participants were probed further, if the interviewer felt an explanation needed clarification or elaboration. However, the interviewer avoided asking leading questions that might influence a response. Statements like "*Explain that idea a bit more*" or "*You said...tell me what you mean by that*" are clarification and elaboration statements that were used to encourage the participant to expand upon an idea. It also was a way to ensure that the interaction gave the team a relevant and accurate picture of the participant's understandings.

A variety of data sources was used during the interview, including drawings, card sorts, and the use of models. All interviews were audio-taped and videotaped. The interviewers noted and recorded observations during the interviews. Interviews were transcribed for data analysis by the researcher. Themes and patterns that emerged from the data were noted and described in order to create a picture of the participant's understanding of lunar concepts. See Table 3.2 for an overview of the interview tasks.

The interviews consisted of six tasks that assessed specific lunar understandings:

- the observable shapes of the moon (Task 1)
- how these shapes change during the lunar cycle (Tasks 2,3, and 6)
- the cause of the change (Tasks 4 and 5).

See Appendix C for the student interview protocol.

Task 1: drawing shapes.

Participants were asked for Task 1 to draw all of the shapes of the moon that they expect to see (pre-instructional intervention) or had seen (mid- and post-instructional intervention). This information was used to determine the participant's knowledge of observable moon shapes. See Appendix D for drawing sheets.

Task 2: predicting patterns of change.

Participants were asked for Task 2 to predict whether the shapes of the moon will change in a predictable pattern (pre-instructional intervention) or did change (mid- and post-instructional intervention). This task was used to determine the participant's knowledge of regularly observable moon shapes and patterns of changes in the phases.

Task 3: drawing sequence of lunar phases.

If the answer for Task 2 was affirmative, and the participant expected to observe lunar changes in a predictable pattern, the participant was asked to complete Task 3. There was no Task 3 on the pre-, mid-, or post-instructional intervention assessments for the participant who did not make an affirmative prediction on Task 2. For Task 3 the students were asked to draw the sequence of the moon shapes (pre-, mid-, and post-instructional intervention).

Task 4: explaining the cause of moon phases.

For Task 4 students were asked to explain what they thought caused the changes (pre- and post-instructional intervention).

Task 5: using models to explain the cause of phases.

For Task 5 students were asked (pre- and post-instructional intervention) to use three-dimensional models (analogical models) of the Earth, moon, and sun to accompany their causal explanations. Using the three-dimensional models of the Earth, moon, and sun, the participants had an opportunity to demonstrate perspectives other than the Earth perspective. The model of the sun was a 10-cm yellow plastic sphere that rested in a cradle. The Earth was represented with a 3-cm sphere and the moon was represented with a 1-cm white sphere. A pin located in the northern hemisphere of the Earth model represented our community. The representative moon model had a toothpick inserted for easy handling (Trundle, et al., 2007a).

Task 6: card sorting.

Task 6 consisted of a card sorting activity in which students were asked (pre- and post-instructional intervention) to order eight representative lunar phases in the scientifically accurate sequence. This task was taken from the McDermott (1996) materials and modified for younger students. The instruction in *Physics by Inquiry* for sequencing moon phases was changed from making drawings of the eight shapes and sequencing them to arranging the eight cards with the shapes already created on them (Trundle et al., 2007b).

Tasks	Pre-Instruction	Mid-instruction	Post-Instruction
1 Draw shapes	X	X	X
2 Moon shapes change	X	X	X
3 Draw in sequence	X	X	X
4What caused change	X		X
5 Use models and explain causes	X		X
6 Card sorting activity	X		X

Table 3.2 Interview Tasks

Student Work

Various data sources of student work were available for analysis. For example, the children's individual moon journals, the personal moon calendar, the community

moon calendar, and other forms or responses that represented a student's learning were used as data sources for the study.

Students recorded written responses in the form of statements or questions and/or drawings (diagrams) at least once a week in their moon journal. Those responses were either prior to or after our weekly lunar observation sharing sessions, other activities, and group discussions.

The student's responses were placed by the participant in a personal Moon Journal, which consisted of a three-pronged folder with blank paper. The journal, which was kept in a defined space within the room, was used for observations and reflections of how the student's knowledge was interpreted and how understandings evolved over time.

Each student updated his/her personal moon calendar daily (Appendix A). The moon calendars (3) were kept in the Moon Journal. Each moon calendar had thirty-one rectangular blocks (one for each day of the month). In each block was a circle representing the moon with three lines under each circle for the *date*, *time* (of observation), and *direction* (cardinal direction of observed moon).

All notes taken by the participant observer of student interactions, transcriptions of videotaped and audio-taped interactions during small and whole group activities were used as data sources.

Classroom Observations

Classroom instructional activities were audio-taped and videotaped by the participant observer for transcription. Activities, for example, included the lunar data gathering that was completed collaboratively by the children. Other activities warranted

field notes, like informal discussions that occurred during lunar data analysis.

Transcribed audio-tapes, videotapes, and field notes provided data that were used in the analysis of student understandings.

Data Analysis

Constant-comparative method was used to analyze the interview and written response data (Strauss & Corbin, 1994). The system that Trundle et al. (2002) developed for data analysis was used to identify criteria to describe and code scientific understanding and possible alternative conceptions that students held. New codes were added to the analysis, as they emerged from the data. The ongoing process of constant comparative analysis uncovered gaps, omissions, and inconsistencies in the data (Glaser, 1965). This type of analysis was essentially a method to describe and explore a phenomenon and facilitate making comparisons. The constant comparative analysis has been used with other science content areas such as tides (Ucar, Trundle, & Krissek, 2007), particulate nature of matter (Adadan, Trundle, & Irving, 2006; 2008), and moon phases (Bell & Trundle, 2008; Trundle et al., 2002, 2007a, 2007b).

The constant comparative method included multiple steps, such as: comparison of data within a single interview to a code framework, comparison across one individual's pre- and post-instructional intervention interviews, comparison across individuals within a category, and comparison across interviewers and researcher for inter-rater agreement. Each step will be explained and described in the following sections within this chapter.

Coding System

Before data analysis began, a coding framework was in place. This coding framework was not complete but a starting point or a “partial framework” for this study. The system acted as a guide but did not restrict the coding process. Additional codes that emerged from the data, including field notes, transcribed audio-taped and videotaped interviews and classroom activities, were placed within the framework as needed. The partial framework of coding was used by Trundle and colleagues (2002, 2007a, 2007b) and was developed based upon the knowledge in the conceptual change literature (Hewson & Hewson, 1983; Vosniadou, 1994; Vosniadou & Brewer, 1992; 1994). The framework facilitated analysis and standardized coding. See Appendix E, the Coding sheet for the drawings of moon shapes and patterns. Also, see Appendix F, Coding sheet for cause of the moon phases.

The scientific views of shapes, patterns, and causes of moon phases were used to establish criteria to describe a scientific understanding and possible alternative conceptions that participants held. If a participant expressed all four critical elements that define the scientific conception for the cause of moon phases, that participant was judged to hold a scientific conceptual understanding and the participant’s responses were categorized as scientific. If a respondent reported a subset but not all of the four critical elements, the participant would be judged to hold scientific fragments. Alternative conceptions are models that are at variance with the scientific model of understanding (Vosniadou, 1991). Participants may develop alternative conceptions based on everyday experiences or when entrenched naïve knowledge conflicts with scientific conceptions (Vosniadou & Brewer, 1992, 1994). If a participant responded

with a non-scientific explanation about the cause of moon phases, the individual's conception was categorized as alternative. A student's responses that were not clearly defined as being in any one type of conceptual understanding or included many alternative explanations were categorized as alternative fragments. See the following table for the types of conceptual understanding and the criteria and codes used in the present study, Table 3.3.

Type of Conceptual Understanding	Criteria and Codes
Scientific	Half of the moon is illuminated by the sun [Sci Half] The portion of the illuminated half seen from earth varies over time [Sci See] The relative positions of the earth, sun, and moon determine the portion of the lighted half seen from earth [Sci EMS] The moon orbits earth [Sci Orb]
Scientific with Alternative Fragment	Met all four scientific criteria, but also indicated belief in one alternative fragments listed below
Scientific Fragments	Included a subset but not all of the four scientific criteria
Alternative Eclipse	The earth's shadow causes the moon phases [Alt Eclipse]
Alternative Earth's Rotation	The earth's rotation on its axis causes the moon phases [Alt Rot]
Alternative Heliocentric	Moon orbits the sun but not earth. In other words, the moon and earth orbit the sun independently of each other. When the sun gets between the earth and moon, the moon is in the new moon phase [Alt Helio]
Alternative Geocentric	Sun and moon orbit the earth, causing moon phases [Alt Geocentric]
Alternative Clouds	Cloud cover causes moon phases [Alt Clouds]
Alternative Planet	Planet's (other than earth) shadow on moon causes moon phases [Alt Planets]
Alternative Distance between the Moon and Sun	Varying distance between sun and moon. When moon is closer to sun the moon is full. When it is further away from the sun, the moon is in the new moon phase [Alt Distance]
Alternative Fragments	Include a subset or subsets of alternative conceptual understandings.

Table 3.3 Coding System (Trundle et al., 2002).

Constant Comparative Analysis and Coding

Participants' pre-, mid-, and post-instructional intervention responses were transcribed, analyzed and compared to the scientific views of lunar phases and causes of the lunar phases. These data, once coded, created participant profiles that were used to compare pre-, mid-, and post-instructional intervention understandings within the individual, across the group for specific lunar concepts (i.e. shapes, sequences, and causes of lunar phases), and within the groups at multiple times (i.e. pre- to mid-instructional intervention comparisons).

The first step in using the constant comparative analysis method was comparing the data within a single interview to the coding system based on the scientific model of lunar phase concepts. The transcripts of each videotaped and audio-taped interview was analyzed and matched within the coding system by the teacher-researcher. New codes appeared during the analysis. Secondly, the researcher checked for consistency of the responses within one interview for all six tasks. Looking at codes throughout the interview allowed the researcher to identify the participant's type of conceptual understanding.

The third step of data analysis required comparison across one individual's pre- and post-instructional intervention interviews. Collecting data at multiple points during the study provided the researcher with information about any changes in a participant's lunar concept understanding.

The next step of the constant comparative analysis involved comparing the data across individuals within a category at multiple points during the study. This analysis focused on a particular category. For example, an individual participant's conceptual understanding of lunar sequences was compared to other individuals within the study. The data provided information that was used to summarize the overall conceptual understanding within a category.

The final step of the analysis involved comparing a participant's conceptual understandings before and after the instructional intervention in order to discern any conceptual change.

For the present study, comparisons were made at five levels, which are presented in Table 3.4.

Comparison	Aim of Comparison
Data from a single interview were compared to the coding scheme	To verify the consistency of answers, to code the transcripts, and to add new codes to the framework.
Codes were compared within each interview.	To determine the alternative and scientific and alternative conceptions.
Codes within a single interview were compared to types of conceptual understandings.	To categorize participants based on their conceptual understandings
Comparisons were made between the participants' conceptual understandings.	To summarize the overall conceptual understanding categories with percentages across the group.
Comparisons were made between the conceptual understandings before and after instruction.	To distinguish conceptual change.

Table 3.4 Levels of Comparisons for the Constant Comparative Data Analysis (Based on Ucar, p.96, 2007).

Creation of Categorization

There are four types of conceptual understandings that have been identified in previous research (Trundle et al., 2007b): scientific, scientific fragments, alternative, and alternative fragments. These types of understandings found in Table 3.5 were used to categorize the themes found in the data after coding, which included the types of conceptual understandings and the criteria used to describe each type.

Categories of Conceptual Understandings	Criteria
Scientific	All four elements include: • Half the moon is illuminated by the sun • The portion of the illuminated half seen from Earth varies over time. • The relative positions of the earth, sun, and moon determine the portion of the lighted half seen from earth. • The moon orbits earth.
Scientific fragments	Included a subset but not all of the four scientific critical elements
Alternative	Conceptual understandings that at variance with scientifically accepted norms.
Alternative fragments	Included a subset or subsets of alternative conceptual understandings

Table 3.5 Types of Conceptual Understandings and Criteria (Trundle, et al. 2007b).

Each category reflects the types of conceptual understanding that have been described in previous science content areas involving student conceptual change (Adadan et al. 2006, 2008; Bell & Trundle, 2008; Trundle et al., 2002, 2007a, b; Ucar et al., 2007). These categories were the guides for identifying and comparing data, but were not restrictive. The categories were revised or amended in response to the data.

Coding Reliability

In an effort to make the findings reliable, a research team consisting of the principal researcher (participant observer) and two other experts independently reviewed and coded portions of the transcripts. Good confidence in the findings was established with the principal researcher and the two experts reaching 97.1% inter-rater agreement when coding the shapes and sequence pre- and post-assessment interview responses. The three individuals reached 92.8% inter-rater agreement when coding the cause of moon phase responses on the pre- and post-assessment interview responses of the children.

In addition to the qualitative analysis of the data, nonparametric tests, the McNemar test and the Wilcoxon Signed Ranks Test, were used to analyze students' drawings and changes in their understanding from the pre- to post-test. To make statistical analysis possible participants' pre and post conceptual understandings were scored with a scoring rubric (see Appendix G), designed by Sackes & Trundle (2009). Participants were given scores ranging from 0 to 10 based on the number of scientific elements and alternative mental models included in their conceptual understanding.

Trustworthiness

Trustworthiness or research validity for this study was established carefully. Lincoln & Guba (1985) suggest using the constructs of *credibility* and *dependability* to ensure the research is valid and is worthy of trust.

The strategies that were employed to establish credibility for the study were: prolonged engagement, persistent observation, and triangulation (Lincoln & Guba, 1985). Prolonged engagement, according to Lincoln and Guba, involves the

“investment of sufficient time to achieve certain purposes; learning the culture, testing for misinformation introduced by distortions either of self or of the respondents, and building trust” (p. 301). The study took place within the participant observer’s classroom, in which she has taught throughout the academic year of the study. The researcher knew many of the participants for two years in this multi-age classroom. The history between the participants and the researcher was well-established.

Another strategy used to establish credibility in the present study was persistent observation, which involved identifying “those characteristics and elements in the situation that are most relevant to the problem or issue being pursued and focusing on them in detail” (Lincoln & Guba, 1985, p. 304). Persistent observation throughout the study provided depth of data to the findings. Videotaped and audio-taped interviews, participant written responses, observations, and field notes generated multiple layers of data.

The third strategy suggested for adding credibility to this study was triangulation of the data sources. Audio-taped and videotaped transcriptions of the interviews, member checks of the data that was gathered, field notes, and participant writing offered multiple opportunities to receive and analyze the data. Member checking allowed the participant observer to test data and interpretations with the participants. It allowed the participants to confirm or negate the interpretations. This was done informally with statements like, “*You said ...What did you mean?*” Or “*Tell me more about your thought...*” My reflective notes were added to the transcripts. Inter-rater reliability was utilized to determine agreement when coding the responses of the participants. The researcher and two experts from the research team, having experience

in analyzing science education qualitative and quantitative data, reviewed the responses independently to check for agreement when coding. If discrepancies arose, the team reviewed the videotapes and transcripts together, discussed the discrepancies, and reached a consensus.

In order to establish dependability within the data the participant observer needed to include all of the above strategies that were listed: prolonged engagement, persistent observation, triangulation of the data sources, and rich, thick descriptions for replication of the study in different settings. Preparing detailed transcriptions and reflective notes added to the dependability of the study. Dependability was also established with strong inter-rater agreement when a team of three independently coded the children's interview responses related to the shapes and sequences of the moon and the cause of the moon's phases.

Summary

This chapter outlined a descriptive moon phase research study that was completed with Primary students in the context of a traditional science classroom. The chapter described the instructional intervention, which blended McDermott's (1996) science inquiry activities, *Physics by Inquiry*, and the use of planetarium software to promote scientific understanding related to moon phases. The chapter also described the data collection and data analysis procedures that defined the care given to demonstrate a study that adds to the science field.

CHAPTER 4

FINDINGS

Overview

Chapter 4 reports the findings for this study. The data gathered during the pre-, mid-, and post-instructional intervention periods will be referred to as pre-assessment, mid-assessment, and post-assessment data. The findings are reported in three sections, which are aligned with the research questions.

The purpose of the present study was to describe and report the responses of Primary children during a moon study project that included lunar data gathering within an instructional intervention. The inquiry-based intervention and the use of technology to collect lunar data were explored as possible ways to promote scientific understandings about the daytime and nighttime skies, the sequence of lunar phases, and the cause of lunar phases with young children. Three research questions guided the research.

1. What do Primary children know about when the moon can be observed before and after inquiry-based instruction?
2. What do children know about observable moon phase shapes and sequences before, during, and after inquiry-based instruction?
3. What do children understand about the cause of moon phases before and after inquiry-based instruction?

As described in chapter three, a questionnaire was given to individual participants prior to and at the conclusion of the study. The questionnaire was developed to answer the first research question. The instructional intervention was used to guide the children during the lunar data collection, recording, sharing, and analysis period, and during the psychomotor modeling activity (McDermott, 1996). In order to answer research questions two and three, children were given drawing and predicting tasks, and they participated in videotaped interviews. Data were collected prior to, mid-instruction (before the psychomotor modeling activity), and at the conclusion of the study (after the psychomotor modeling activity). The videotapes and drawings were transcribed and coded, based on the participant's responses. The drawings were coded as being scientific or non-scientific, as detailed in chapter three. The codes (Trundle et al., 2002) used to determine the category of conceptual understanding each participant held for the cause of moon phases also were described in chapter three. New codes emerged from the data and were added to the coding scheme.

At the conclusion of the process, the categories of conceptual understanding of the cause of moon phases included: scientific understanding, scientific fragments, scientific with an alternative fragment, alternative, alternative fragments, alternative understanding with scientific fragment, and no understanding. Frequency counts were determined for each category.

Research Question 1: What do Primary children know about when the moon can be observed before and after inquiry-based instruction?

The students responded in writing to the following question about the moon:

When do you see the moon? The questionnaire included other questions about the sun and moon, but only the data from this specific question was used to answer research question 1.

Before Instruction

Before instruction most children did not have scientific knowledge of when the moon could be observed. Many of the participants (16 or 76.2%) knew that the moon could be observed in the nighttime sky sometimes, but only one student (Student 10) knew the moon could be observed sometimes in the daytime sky prior to the instructional intervention.

After Instruction

After instruction most children knew that the moon could be observed sometimes during the day. More than half of the participants (17 or 81%) indicated the moon could sometimes be observed in the daytime sky, and almost all of the participants (20 or 95.2%) reported that the moon could often be observed in the nighttime sky after the instructional intervention. One student did not respond to the question on the post-assessment.

Summary

There was notable change in children's responses to research question 1 after an instructional intervention. Children's knowledge of when the moon can be observed changed. Before instruction 16 students (76.2%) reported that the moon could be

observed at night with one student (5%) stating that the moon could sometimes be observed during the day. After instruction almost all students reported that the moon can be observed sometimes at night. More children (17 or 81%) reported that the moon could be observed sometimes during the day and sometimes during the night.

Research Question 2: What do children know about observable moon phase shapes and sequences before, during, and after inquiry-based instruction?

Observable Moon Phase Shapes

The drawing task was used to answer the question related to student knowledge of observable moon phase shapes before, during, and after inquiry-based instruction. Children were given a sheet of paper and a pencil and were asked to draw all of the shapes of the moon that they expect to observe (pre-assessment) or had observed (mid- and post-assessment) in the sky. The moon phase drawings were coded by the researcher as being either *scientific* or *non-scientific*. These codes were used in prior studies (Trundle et al., 2002) as described in chapter 3. During further analysis, notes were taken and used to define the coding for analysis purposes. Frequency counts were calculated to determine the number of participants recording each of the eight representative moon phases. Omissions of moon phases were not reported statistically, even though they occurred. Omitting a phase was considered less of a deficiency than including a non-scientific shape, since the participant simply may have forgotten to include a specific shape among their drawings. Some participants drew both a scientific and a non-scientific moon shape for one particular shape. In these cases the drawings

for the specific shape were coded as non-scientific. Gibbous and crescent moons were the most problematic for the participants in that the children drew more non-scientific representations of these particular shapes. A non-scientific gibbous moon typically was drawn like a large crescent moon, resembling a partial eclipse moon. Non-scientific quarter moons resembled the partial eclipse moon as well. Crescent moon drawings were coded non-scientific if they were over- or under-articulating in shape (i.e. points extending past the mid-point of the moon). Students did not receive direct instruction related to drawing the phases, nor was attention drawn to the visual details of each specific phase initially. Rather, they simply observed and recorded their observations from images on *Starry Night*.

The results of analyzing and coding the specific moon shapes are reported in Table 4.1. This table shows the number of participants who included the moon shapes in their pre-assessment, mid-assessment, and post assessment drawings.

Moon Phase	Pre-Assessment		Mid-Assessment		Post-Assessment	
	Sci	Non-Sci	Sci	Non-Sci	Sci	Non-Sci
Full	21	0	21	0	21	0
Waning Gibbous	0	11	5	7	13	5
Third Quarter	9	1	14	1	18	1
Waning Crescent	5	11	4	13	14	5
New Moon	8	0	15	0	20	0
Waxing Crescent	2	7	4	11	13	8
First Quarter	8	1	12	0	15	4
Waxing Gibbous	1	4	5	4	11	8

Table 4.1 Frequencies of Participants Drawing Specific Moon Phases (Task 1)

Drawings Before Instruction

Prior to the instruction, all children included at least one alternative, non-scientific phase among their moon drawings. Before instruction all 21 (100%) of the participants included the full moon in their drawings. This result was not surprising because the prompt instructed children to draw a full moon. Other than the full moon, the most common moon phase drawn was the waning crescent, with 16 students (76.2%) including this particular shape. Five students (23.8%) drew the scientific shape, while 11 students (52.4%) drew the non-scientific waning crescent. The least represented moon shape was the waxing gibbous phase, with only five students (23.8%) drawing the shape. Only one student (4.8%) drew a scientifically accurate waxing gibbous, while 4 students (19%) represented a non-scientific shape for this phase. None of the children drew scientifically accurate representations of all of the eight representative moon shapes.

Drawings During Instruction

During the instructional intervention the participants drew more scientific moon shapes. Besides all 21 students (100%) drawing the scientifically accurate full moon, 15 students (71.4%) also included a scientific new moon drawing on the mid-assessment. In addition to the full and new moon shapes, the most common moon shape drawn was the waning crescent phase, with 17 children (81%) including this shape in their drawings. Four children (19%) drew the scientific waning crescent moon shape, while 13 children (61.9%) drew the non-scientific waning crescent. More than half of the participants drew scientifically accurate quarter moons. Fourteen students

(66.7%) drew the scientific third quarter moon and 12 students (57.1%) drew the scientific first quarter moon. Only one participant (4.8%) included a non-scientific third quarter moon. The least common shape drawn was the waxing gibbous phase, with nine children (42.9%) representing this phase. Five of the participants (42.8%) drew the scientifically accurate shape, while four participants (19%) drew the non-scientific waxing gibbous moon. Again, none of the participants drew scientifically accurate representations of all eight moon phases during the instructional intervention.

Drawings After Instruction

After instruction, children drew more moon shapes and represented more scientific shapes among their drawings. All of the 21 students (100%) drew the full moon. In addition to the full moon, the most common moon shape drawn was the waxing crescent, with all 21 students (100%) including this phase. Thirteen students (61.9%) drew a scientifically accurate waxing crescent shape, while eight drew a non-scientific representation of this phase. Twenty children (95.2%) drew an accurate new moon phase. The majority of the students drew scientifically accurate quarter moon drawings, with 18 participants (85.7%) drawing the scientifically accurate third quarter moon phase and 15 students (71.4%) drawing the accurate first quarter moon phase. The least common moon shape drawn was the waning gibbous, with 18 students (85.7%) including the shape in their drawings. Thirteen students (61.9%) drew scientific waning gibbous moon shapes, while five students (42.8%) drew non-scientific shapes for this phase. Almost all of the children attempted to draw all eight phases after the instructional intervention, and more of the children drew scientifically accurate moon

phases. Eight students (38.1%) drew scientifically accurate representations of all eight moon shapes.

Summary of Moon Drawings

Children's knowledge about the observable moon shapes changed during the study as indicated by the number of children drawing representative moon phases and the frequency of scientifically accurate drawings. Prior to the instructional intervention fewer children were likely to include representative moon phase drawings, and children were likely to include at least one non-scientific moon phase among their drawings. During the instructional intervention more children were including representative moon shapes and those drawings were more scientific compared to before instruction. None of the children drew all of the eight representative moon phases in their drawings. The greatest shift occurred after instruction. Children drew significantly more specific moon phases and more of those drawings were scientific. After instruction eight children included all eight scientific representative moon phases in their drawings.

Sequence of Moon Phases

Three data collecting tasks on the pre-, mid-, and post-assessment were related to the knowledge children have concerning the sequence of moon phases. The tasks included predicting/observing whether the shapes of the moon appear in a sequence and drawing the predicted/observed sequence of the moon's shapes. The card sorting task was completed during the interviews which occurred prior to and after the instructional intervention.

Predicting Sequences

Each participant was asked to predict whether the shapes of the moon would change in a predictable pattern (pre-assessment) or did change (mid- and post-assessment) in a predictable pattern over time. If the participant answered affirmatively that the moon's phases would/did change in a predictable pattern, the participant was asked to draw the sequence of the moon shapes for the drawing task. If the participant reported no predictable sequence in the moon's phases, he/she was not asked to draw a lunar sequence.

Before instruction most students believed that the moon's phases appear in a predictable sequence, while after instruction all students reported the moon's phases appear in a predictable pattern. On the pre-assessment 16 students (76.2%) predicted that the moon's shapes would appear in a predictable pattern, while five students (23.8%) predicted that the moon's phases would not appear in a pattern. On the mid-assessment more students predicted that the moon's shapes did occur in a predictable sequence with 18 students (85.7%) affirmatively answering the task. All 21 students (100%) on the post-assessment predicted that the shapes of the moon would appear in a predictable sequence.

Children's responses to whether the moon's phases would change in a predictable pattern changed over the course of the study. Before instruction many children reported that the moon's shape would change with five students indicating that the moon would not change in any predictable way. More had reported that there was a predictable sequence of lunar phases by the mid-assessment. After the instructional

intervention all of the children knew and reported that the moon's phases would appear in a predictable pattern.

Drawing Sequences

For this task participants who affirmatively answered that the moon's phases would appear/appeared in a predictable pattern or sequence were asked to draw the sequence of lunar shapes. These data were relevant to the knowledge children have about the lunar phase sequences. The sequence drawing task revealed what the child knew about the waning and waxing series of the moon phases. Not all eight of the representative moon phases for the waning and waxing series needed to be drawn for the drawings to be considered scientific, but there needed to be enough of the moon shapes to represent the series. Table 4.2 summarizes the findings for the predicting sequence task and the task of drawing moon shapes in sequence.

Sequence	Pre-Assessment		Mid-Assessment		Post-Assessment	
	Sci	Non-Sci	Sci	Non-Sci	Sci	Non-Sci
Predictable Sequence	16 (Yes)	5 (No)	18 (Yes)	3 (No)	21 (Yes)	0 (No)
Moon Waning Series	5	8	4	9	12	8
Moon Waxing Series	4	12	3	11	10	11
Moon Waxing and Waning Series	0	14	0	13	8	12

Table 4.2 Frequencies of Participants Including Moon Phase Sequences

Before instruction.

Without instruction most children's knowledge of the regularly recurring pattern of moon phases was nonscientific. On the pre-assessment task, five (23.8%) of the 13 participants who attempted to draw the waning sequence were judged to have

scientific drawings, while four participants (19%) drew a scientifically accurate waxing series of moon phases. There were no participants who drew both the scientific waning and waxing series of moon phases on the pre-assessment. Most of the children drew non-scientific representations of the waning and waxing moon sequences. Eight of the students (38.1%) drew non-scientific waning moon series and even more students (12 or 57.1%) drew non-scientific waxing moon series.

Below is a drawing of the moon series created by one student during the pre-assessment period. During the interview, the child was asked to predict whether the moons appear in a predictable pattern (See Appendix C for interview protocol). If the child indicated the moon phases appeared in predictable sequence, the child was asked to draw the sequence and order the moon drawings by numbering them. One student (Student 20) drew and numbered the moons that he thought appeared in a sequence. The student drew an alternative sequence, including waning moons in a waxing series. See the drawing Figure 4.1.



Figure 4.1 Student's Drawing of the Predictable Moon Sequence (Pre-assessment)

During instruction.

On the mid-assessment, as reported earlier, 18 participants (85.7%) affirmatively answered that the moon's phases appeared in a predictable sequence, while three students declared the moon's sequence of shapes unpredictable. Although more students indicated that a lunar pattern does exist, fewer students drew scientific moon sequences on the mid-assessment. Thirteen students attempted to draw the waning moon sequence and four participants' drawings (19%) were judged to consistently use a scientific representation, while nine of the students (42.9%) drew a non-scientific

waning moon sequence. Fourteen students attempted to draw a waxing series and three students (14.3%) represented the moon phase scientifically, while 11 students (52.4%) drew a non-scientific waxing series of moon phases. None of the students drew both a scientific waning and waxing sequence of moon phases during the instructional intervention period.

After instruction.

After instruction more children were likely to demonstrate scientific knowledge of the regularly recurring pattern of moon phases, and some of the children were able to draw both the scientific waning and waxing moon phases.

With all of the children (100%) participating in this task, more than half of the students (12 or 57.1%) drew a scientifically accurate waning moon series, while ten students (47.6%) drew a scientifically accurate waxing series. More than one-third of the students (8 students, or 38.1%) were able to draw both a waning and a waxing moon series accurately after the instructional intervention period.

See Figure 2 for the student's (Student 20) post-assessment drawing of the moon phases as an example of a scientific drawing of both the waning and waxing moon phase series.

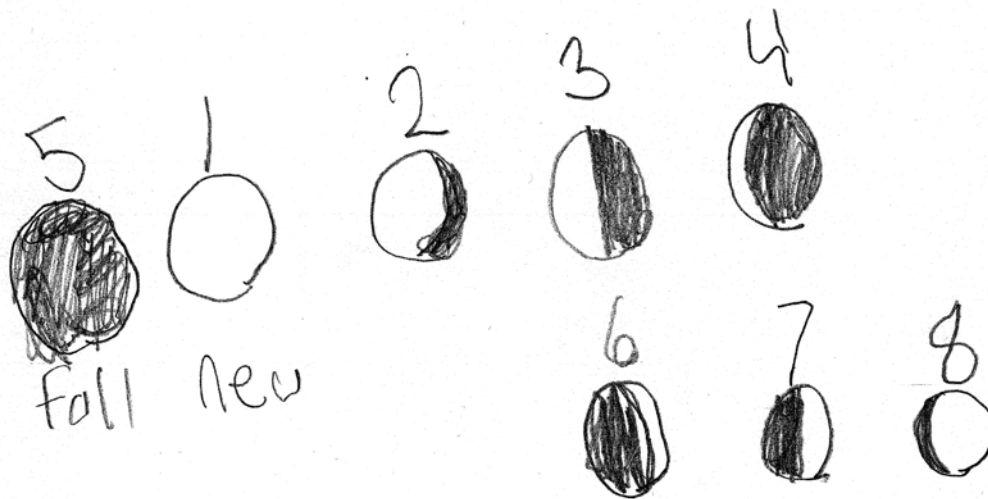


Figure 4.2 Same Student's Drawing of the Predictable Moon Sequence (Post-assessment).

Sequence summary.

In summary the group's performance on this task improved over the duration of the study. The pre- and mid-assessment results for drawing the moon phases in a sequence were similar with many children attempting to draw the waning and waxing moon series. The majority of the patterns were coded as non-scientific. Post-assessment sequence responses were more positive than the pre- and mid-assessment findings. All of the children affirmatively reported that the moon's phases appear in a reoccurring pattern, and most attempted to draw both the waning and waxing moon series.

Moon Shapes and Sequences

In looking at the children's understanding of both shapes and sequences, none of the children drew both scientific shapes *and* sequences before instruction, but five children (23.8%) drew both scientific shapes *and* sequences after instruction.

Card Sorting Sequences

The card sorting task was given during the pre-assessment and post-assessment interviews. This task was relevant to children's knowledge about the sequence of the moon's shapes.

The students were given eight randomly shuffled cards (4x4 in.) each containing one representative moon shape. Each moon shape was circular with a portion of the circle colored in orange to highlight the illuminated moon phase. There was an arrow pointing up at the top of each card signaling the correct orientation. Children were given the cards to organize into the lunar phase sequence. They were told to place the cards in order, beginning with either the full moon or the new moon. At the end of the task children were asked to point out the first moon in the sequence. The task process was videotaped and coded as either *scientific* or *non-scientific*.

Before Instruction

Prior to the instruction few children were able to sort the cards in a scientifically accurate moon series. Prior to the lunar data collection, recording, and analyzing period and the inquiry-based instruction, four students (19%) placed the cards in scientific waning and waxing sequences. Seventeen students (81%) placed the cards in non-scientific sequences. Among the 17 students who produced non-scientific sequences, two interesting patterns emerged in the data. Five students (23.8%) arranged the cards either with waxing moon shapes organized in a waning sequence or waning moon shapes organized in a waxing sequence. Other children (4 or 19%) sorted cards

where they grouped mirrored moon shapes with both gibbous moons, both quarter moon, and both crescent moons together.

After Instruction

After instruction more than half of the students arranged the cards in scientifically accurate patterns. Like the task for the sequence drawings of the waning and waxing moon series, the card sorting task results reflected a positive change after the instructional intervention. After the lunar collection, recording, and analyzing period and the inquiry-based instruction, 12 participants (57.1%) placed the cards in scientific sequences, while nine participants (42.9%) presented non-scientific representations of the waning and waxing sequences.

Summary of Card Sorting Activity

There was a positive change in the children's ability to sort the eight representative moon phase cards after the instructional intervention. Before instruction only 4 students placed the cards in scientific waning and waxing sequences and after the instruction 12 students were able to perform the task accurately.

The results of both the drawing sequences task and the card sorting task showed positive changes from pre- to post-assessment. However, the children demonstrated greater change in the card sorting task.

Research Question 3: What do children understand about the cause of moon phases before and after inquiry-based instruction?

Types of Conceptual Understandings

Children were interviewed both before and after the instructional intervention in order to determine the conceptual understanding each child held regarding the cause of moon phases. The interview protocol was used in previous studies (Trundle, et al., 2002, 2004, 2006, 2007a). Types of conceptual change are described in this section. Seven categories, as defined in chapter 3, were used to classify coded responses by types of conceptual understanding. The categories are scientific understanding, scientific understanding with an alternative fragment, scientific fragments, alternative understanding with a scientific fragment, alternative understanding, alternative fragments, and no conceptual understanding (no understanding is evident at this time). Each category will be briefly described and excerpts from the transcriptions, taken from the pre- and/or post-assessment interviews, will be provided as an example for each type of conceptual understanding. The interviewer's questions and comments will be marked "I", and the student's response will be marked with the student's number (S#). Codes are inserted into the student responses, bolded and within parentheses. The children used analogical models of the earth (E), sun (S), and moon (M) during the interviews. The initials for the models will be used to demonstrate their relative position in space.

Scientific Conceptual Understanding

A participant's conceptual understanding was identified as scientific for the cause of moon phases if he/she expressed all four critical elements that define the

scientific conception. Those elements include: half the moon is always illuminated by the sun (Sci_Half); the portion of the illuminated half, as seen from earth, varies over time (Sci_See); the relative positions of the earth, sun, and moon determine the portion of the lighted half seen from earth (Sci_EMS); and the moon orbits earth (Sci_Orbit) (Trundle et al., 2002).

At the time of the pre-assessment interview, none of the twenty-one participants demonstrated a scientific conceptual understanding of the cause of moon phases. However, at the conclusion of the instruction eleven participants (52.4%) were identified as holding a scientific conceptual understanding. An excerpt from one participant's responses, categorized as scientific conceptual understanding after the instructional intervention, is included.

- I: Using the models, use and explain the cause of the moon's phases.
- S20: *The student accurately arranged the eight phases, correctly named each phase beginning with the new moon, and moved the moon in an accurate orbit of the earth. This is the new moon. The student placed the moon model between the sun and earth models (Sci_EMS). He moved the moon in a counterclockwise movement around the earth model (Sci_Orbit). This is the backward C (waxing crescent) because the sun is shining here. The student points to the side of the moon facing the sun. The student continued to move the moon around the earth to a first quarter position (Sci_EMS). And you go all the way over here and the sun is shining on this side. He points to the side of the moon facing the sun. And that's a half moon. The student continued to move the moon model to a full moon position. And you come up here. He is holding the moon above the plane of the sun and earth in the full moon position. (Sci_Orbit, Sci_EMS). The student continued to move the moon model around the earth model in a complete lunar cycle (Sci_Orbit).*
- I: *The interviewer showed the student the drawing of a full moon. This is what we call a full moon...Arrange the models so we would see a full moon.*
- S20: *The student arranged the moon model in a full moon position*

(Sci_EMS).

I: Why would that be a full moon?

S20: The sun shines all the way here. *The student identifies the illuminated side of the moon facing the sun and the earth*

I: Arrange the models so there would be a new moon.

S20: *The student accurately arranges the models to represent a new moon phase with the moon between the sun and earth models* **(Sci_EMS).**

I: Why would that be a new moon phase?

S20: Because the sun is just shining on this side. *He points to the side that is facing the sun, the side not visible from the earth. Not shining on this side. The student points to the side facing earth.*

I: Could we see a moon like this? *The interviewer shows the student a drawing of the moon in the waning gibbous phase.*

S20: Yes. That is the waning gibbous. *The student places the models in the waning gibbous moon phase. The sun is shining here. He points to the side of the moon facing the sun. It (the illumination) covers half of the moon* **(Sci_Half)**, but all we can see is just the gibbous **(Sci_See).**

Scientific Understanding with an Alternative Fragment

A scientific understanding with an alternative fragment is a category in which the participant holds all four key criteria of a scientific understanding plus one alternative understanding, the earth's rotation on its axis also contributes to causing moon phases.

There were no participants demonstrating scientific understanding with an alternative fragment during the pre-assessment interviews. Two participants (38.1 %) held this type of conceptual understanding after the instructional period. Besides providing all four critical elements about the cause of moon phases, the participants indicated that the rotation of the Earth **(Alt_Rotation)** also contributed to the cause of moon phases. One participant's responses that were categorized as scientific conceptual understanding with an alternative fragment follows.

I: Talk to me about what causes moon phases.

- Why is the moon sometimes full and other times not full?
- S18: The moon is always half (lighted) (**Sci_Half**)... you see different moons because you are in different angles (**Sci_See**, **Sci_EMS**)...
- I: Use these models... Show me and tell me what causes moon phases.
- S18: *The student used the models to demonstrate the moon's orbit around the earth (Sci_Orbit).* Right here is where you can see a half moon (first quarter). *Student arranges models so that the quarter moon is visible from student's perspective (Sci_EMS)*
- I: And why would that be a half moon?
- S18: The sun is reflecting here (on the moon). *The student points to the side of the moon facing the sun.* And we are right here, so it would look like a half to us (**Sci_See**).
- I: Show me something other than a half moon.
- S18: *The student arranged the models to the new moon position (Sci_EMS).* It would be a new moon and we couldn't see it.
- I: I want you to arrange the models so that there would be a new moon.
- S18: *The student arranged the models Sun-Moon-Earth alignment or the new moon position (Sci_EMS).*
- I: And why is that the new moon
- S18: If we are facing away we can't see anything, because it is all on this side of the moon. *The student points to the side of the moon facing the sun.*
- I: What is on that side?
- S18: All of the sunlight is.
- I: Could we see a moon that looks like this? *The moon is in the full moon position, but the pin signifying our community is facing away from the moon.*
- S18: I think it is a crescent...
- I: And why would that be a crescent moon phase?
- S18: When we are at this angle and we look over here, *the student points from the pin to the moon*, all we could see is this, here (sliver of the moon).
- I: What if I do this? *Interviewer rotates the axis of the earth so that the pin is facing the moon and the models remain in the same full moon position.*
- S18: It is a full moon (**Alt_Rotation**).

Although the student has all of the critical elements that indicate she has a scientific understanding of the cause of moon phases, she holds an alternative concept that the earth's rotation on its axis also contributes to the cause of moon phases. When the moon is in the full moon position, the student identified the moon as full only if the pin signifying our community is pointing to the moon. If the pin was not pointing toward the moon, the student identified the moon phase as being a crescent. The student used the pin's location relative to the moon to predict the moon's phase.

Scientific Fragments

If a student reported a subset but not all four critical scientific elements, the student's conceptual understanding was categorized as a *scientific fragment* type of conceptual understanding. None of the students held this type of conceptual understanding before the instructional intervention (pre-assessment interviews). One participant (4.8%) was identified as having scientific fragments after the instruction (post-assessment interviews). An excerpt follows from one participant's responses that were categorized as scientific fragment type of conceptual understanding.

- I: What makes the moon look different at different times?
S14: Well, I'm not completely sure about this...Sunlight goes onto the moon, so it lights up, but so only... *She hesitated.* We did this experiment. So if this was the moon (*the student turned so that she could extend her right arm behind her chair*) and the sun was right here (*the student extended the other arm in the opposite direction*) this would be the full moon. *The student represented the earth. She described the full moon position or Sun-Earth-Moon or S-E-M.* So when I keep turning more and more there are different moons (moon phases). *As the student talked, she moved her right fist (moon) counterclockwise from behind her body so that it was in front of her body (earth) but between her left fist (sun) and body (sun).* This would be the new moon (**Sci_EMS**). And this would be the full moon S-E-M (*sun-earth-moon alignment, which she attempted to demonstrate by*

continuing to move her right fist counterclockwise as far as she could reach. So when I keep turning (the moon, which she demonstrated using her right hand), there are different moons (Sci_Orbit). The student demonstrated the orbit of the moon (her right hand) around the earth (her body) with the sun at her front. The student moved her right hand (moon) in a counterclockwise motion around the earth (her body) (Sci_Orbit).

I: So why are there different moons?

S14: Because the sunlight is reflecting off a different place. Then this is the new moon. *The moon representation is between the earth and the sun...* until we see a full moon (Sci_See). *The student moved her hand (moon) around the complete cycle of the phases. The student is given the models to use with her explanation. Sun is reflecting behind it (moon), we would see nothing. We can't really see it (the new moon)*

I: *The student is given the models of the sun, earth, and moon. She is shown a drawing of the waning crescent. Could we see a moon that looks like this?*

S14: Yes. It's a backwards C. I would guess it would look like this. *The student places the moon in the waning crescent position (Sci_EMS).*

I: Could we see a moon that looks like this? *The student is shown a waxing gibbous moon drawing.*

S14: That's a gibbous moon. *She places the moon model in the waxing gibbous position (Sci_EMS). Sunlight goes on the moon here. The student points to the side of the moon facing the sun. It is not quite a full moon.*

I: Using the models show me a complete cycle of the moon's phases.

S14: *The student demonstrates the complete cycle of the moon beginning with the new moon and moving the moon in a counterclockwise movement around the earth until the moon is back to the new moon position (Sci_Orbit).*

The student has given three of the four critical scientific elements, but never said that the moon is always half lighted. She did point to the back of the moon when she was showing the interviewer the new moon phase and made a reference to us seeing nothing, but did not finish telling about the back side of the moon, the side toward the sun which would be illuminated.

Alternative Conceptual Understanding

Alternative conceptual understandings are at variance with scientific views. This type of understanding was further coded to determine the specific alternative understanding each participant held. For example, alternative understandings could be coded as alternative eclipse model (Alt_Eclipse) and (Alt Eclipse with Sci Frag), alternative Earth's rotation model (Alt_Rotation), alternative heliocentric model (Alt_Helio), alternative geocentric (Alt_Geocentric), alternative cloud (Alt_Cloud), or alternative other (Alt_Other) models. These specific types of conceptual understandings will be discussed further and explained in detail with the excerpts representing the child's conceptual understanding.

Alternative understanding was the most common type of conceptual understanding on the pre-assessment interviews. Sixteen participants' (76.2%) responses were categorized as alternative conceptual understanding on the pre-assessment. Only six participants' (28.6%) responses were categorized as alternative conceptual understanding on the post-assessment interviews.

Alternative eclipse.

In this study six participant's (28.6%) conceptual understanding on the pre-assessment interviews and one participant's (5%) conceptual understanding on the post-assessment interview were categorized as an alternative eclipse understanding. Participants identified as holding this type of conceptual understanding reported or demonstrated that the earth's shadow causes the moon's phases. A representative excerpt of this type of understanding follows.

I: What do you think causes the moon's phases?

- S10: The shadows on the moon (**Alt_Eclipse**) ...the shadows creep over it.
- I: The shadows?
- S10: Like the sun casting shadow over it.
- I: Use the models and explain how the moon's phases change.
- S10: This is the new moon. *The student arranges the models Sun-Earth-Moon alignment or S-E-M, which is the full moon position. There is no light on it at all because the earth is blocking (Alt_Eclipse).*

A subset of the alternative conceptual understanding category is identified as an alternative understanding with scientific fragment.

Alternative understanding with scientific fragment.

Before instruction four participants (19%) believed that the earth's shadow blocked the moon causing the phases All four students in this subset held the same scientific fragment, the moon orbits the earth (Sci_Orbit). An excerpt highlighting this subset is included:

- I: What makes the moon look different at different times?
- S5: The earth orbits the sun and the moon orbits the earth.
- I: *The interviewer gives the student the models and asks the student to arrange the models.*
- Show and tell me what causes moon phases.
- S5: *The student arranges the models in a full moon position (an eclipse position). The earth is here, so the moon is here. That makes there be no moon.*
- I: Why is there no moon?
- S5: None of the sun's light can get to the moon. *The student demonstrates how the rays come from the sun and hit the earth.*
- I: Why can non of the sun's light get over there (to the moon)?
- S5: The earth is blocking it (the sun's light) (**Alt_Eclipse**).
- I: So what phase of the moon would that be?
- S5: The new moon.
- I: Show me another moon phase.
- S5: *The student places the models in a waning gibbous moon phase. It would be something like a half moon or something.*
- I: Why would that be a half moon?
- S5: Because only part of the earth is blocking (the sun's rays onto

the moon) (**Alt_Eclipse**).

I: Show me a complete moon cycle.

S5: This is the new moon. *The student begins in the full moon position and moves the model counterclockwise into the third quarter moon, to the new moon, and back to the full moon position* (**Sci_Orbit**).

Alternative rotation.

Three participants reported that the moon's phases are caused by the earth's rotation on its axis. An excerpt from one student's pre-assessment interview follows.

I: *The interviewer gave the student models of the moon, sun, and earth. Show and tell me how sometimes the moon is full and sometimes it is a new moon. .*

S7: *The student placed the sun, earth, and moon models in a waning crescent position. Then he turned the pin, signifying our community, directly toward the moon. And that causes a full moon. And every 24 hours the earth turns and moves a little...and then it (the sunlight) will reflect off a different part* (**Alt_Rotation**).

I: Arrange the models so that we would see a new moon.

S7: *The student rotates the earth model so that the pin signaling our community is pointing away from the moon, but leaves the sun and earth models in the same place* (**Alt_Rotation**).

I: Why would that be a new moon?

S7: *Because (our community) is facing the back. The student points to the side of the earth facing away from the moon. The light of the moon gets here first. The student left the moon in the waning crescent position. He points out that the light from the sun reflects off the moon and onto the earth, but we do not see the light because (our community) is on the side away from the moon. The portion of the earth facing the moon would see a full moon.*

I: Could we see a moon that looks like this? *The interviewer shows a drawing of the crescent moon.*

S7: Yes. *The student turns the earth's axis and leaves the sun and moon in the same place* (**Alt_Rotation**).

I: *The student is asked by the interviewer to show a complete cycle of the moon's phases.*

S7: *The student has the sun, earth, and moon models arranged in the waning crescent phase. He turns the pin to demonstrate each of*

*the eight phases, while leaving all of the models in the same space (**Alt_Rotation**). First comes a full moon (pin directly in front of the moon). Then comes the third quarter moon. Student turns the pin on the earth model away from the moon. Then comes the new moon.*

The student continues to rotate the earth's axis so that the pin, signifying our community is at different angles relative to the moon. Both the moon and sun remained in permanent positions.

Alternative clouds.

One participant on the pre-assessment interview indicated that clouds covered part of the moon, making its shape change (S11). This student insisted that the clouds block the moon and that causes the moon's shape to change in appearance. If the moon is full, there are no clouds to obscure the moon. Conversely, when we see nothing (the new moon), the clouds are blocking the moon.

S11: That is what also makes a half moon. *The student moves the clouds (cotton ball) over the pin on the earth that denotes our community. Clouds are blocking (**AltCloud**). You can still see it (the moon), but it is making part of it you can't see. Clouds are blocking it.*

Alternative heliocentric.

One student on the pre-assessment interview explained that the earth's orbit of the sun, a heliocentric view, caused the moon phases. In this model the student had the moon and the sun in stationary positions. Due to the earth's orbit around the sun the earth and moon may be on opposite sides of the sun, and at other times the earth may be orbit between the sun and the moon. At the beginning of the interview the student explained that a full moon would be seen when the moon is between the earth and the

sun as the earth orbits the sun (**Alt_Helio**). Later using models, the student demonstrated and explained that a full moon occurs when the earth is between the sun and the moon (S-E-M) and the moon remains stationary. The individual (S20) explained that, as the earth orbits the sun, when the sun gets between the moon and the earth, and the moon is considered a new moon.

- I: I want you to talk to me about what happens with the moon's shape.
- S20: It sort of depends upon where the world and the moon are. Depending on the sun, because the moon reflects off the world.
- I: Arrange the models so we have a full moon.
- S20: *The student arranges the models in a Sun-Moon-Earth alignment, the new moon position.*
- I: Why would that be a full moon?
- S20: The sun shines through and goes over and under and it sort of lights up the moon. The whole moon is light.
- I: This is a new moon. *The interviewer holds a drawing of a new moon phase.* Arrange the models so that we have a new moon phase.
- S20: *The student places the earth on one side of the sun and the moon on the other.*
- I: Why would this be a new moon?
- S20: Because we can't see the moon at all.
- I: And why can't we see the moon at all?
- S20: 'Cause the moon is over here and the world is over there. *The student points to the moon model on one side of the sun model, and then points to the earth model on the other side of the sun model.*
- I: *The student is asked to demonstrate a full lunar cycle.*
- S20: *The student moved the earth in its orbit around the sun. As the earth orbited the sun, it passed between the sun and the moon and at one point the sun was between the earth and the moon. The sun and moon models never moved during the complete moon cycle (Alt_Helio).*

When asked to show one complete moon cycle during the interview, the student placed the sun in the center with the moon at a distance. The student then proceeded to move the earth in an orbit around the sun, passing between the sun and the moon

(Alt_Helio). The moon and the sun remained in fixed positions while the student demonstrated the lunar cycle.

Alternative geocentric.

In one student's geocentric explanation she reported that the sun moves around the earth.

I: Using the models show and explain how the moon's phases are caused.

S8: *The student demonstrates how the moon and the sun move around the earth. The student had the earth in a fixed position. The sun and moon models are on opposite sides of the earth. The student moves the sun and moon models in a counterclockwise movement around the stationary earth model. Because the sun goes around we get different kinds of moons (Alt_Geocentric).*

I: Arrange the models so that we would see a full moon.

S8: *The student arranges the models in the waning gibbous position.*

I: Why would that be a full moon?

S8: *The shadow of the sun (moving hands from the sun to the moon may mean sun's rays) is going down to the moon. The student explains that the people in our community would see the full moon because the light is reflecting off of the moon onto the pin (our community). The pin is facing the moon.*

I: Show and tell me about a complete moon's cycle.

S8: *The student moves only the sun model clockwise around the earth, while leaving the earth and the moon models stationary (Alt_Geocentric). The sun passes between the earth and the moon. This is the quarter moon. She has the moon in the waning crescent position. And this is the one-third moon. The student has the moon in the waning gibbous position.*

Using the models, the student represented one complete moon cycle by passing the sun between the earth and the moon in one revolution of the sun around the earth. The earth and the moon model remained in fixed positions.

Alternative other.

Another large category of alternative conceptual understandings were coded as *Alternative Other*. Participants' responses that did not fit into an existing category of codes were coded as Alternative Other (**Alt_Other**). These new types of responses emerged from the pre-assessment interviews. When the responses were coded in this category, notes were taken and used during the analysis of the data. The following Alt other categories included Anthropomorphism and the Sky.

Anthropomorphism or giving life to an inanimate object (the moon) appeared in two pre-assessment interviews (S12, 15). One participant described the moon as having holes that opened and closed. When the holes were open, the moon let out more light.

- I: You drew some moons. Tell me about the holes in the moon again.
- S12: Well, the holes are like a little circle, a little sphere. Holes means that it shows light coming out of the moon, so you can actually see it (the moon).
- I: You drew a full moon and then you said another moon looked like a "D". Tell me how that happens.
- S12: During the night it changes. It turns into a "D", then half "D", and then... Usually it's a half moon.
- I: What makes it change?
- S12: Well, what makes it change. Um-m. The holes. Sometimes it feels weird and it feels like it wants to change (**Alt_Other-Anthropomorphism**)

The student has given the moon lifelike qualities. The moon, according to the student feels weird and wants to change. The moon decides the amount of light that comes out of the holes. Later in the interview, the student uses the models and talks about the moon being tired.

- I: This is what we call a new moon. *The interviewer shows the student a drawing of the new moon.* Can you show me how that might happen?

S12: Okay, See the sun? Earth. Sun sets down and the moon comes up. It doesn't have no color. It's white. And its holes are tired from the light. So it stays without no light (**Alt_Other-Anthropormorphism**).

Another student talked about the moon as "aging". When the moon was young, it was full, and when it was old, the moon became little.

S15: The new moon, it's all round and when it gets old, it disappears.

I: What makes it disappear?

S15: Probably because it's getting old (**Alt_Other-Anthropormorphism**). And when it's getting little, it is probably getting really old. Eventually it makes a new one, and that's the moon cycle.

Another alternative conceptual understanding that was coded as being Alternative Other included the sky and how it related to the moon's phases. The student (S17) reported that the sky, which was external to the earth and moon, covered part of the moon, causing the moon's phases.

I: What makes the moon look different at different times?

S17: I think the sky goes over the moon... we don't always see the moon...

I: *Models of the sun, earth, and moon are given to the student. She is asked to use the models in her explanation about the cause of moon phases. A strip of paper is provided to the student with the other models, as the sky model.*

Do you want to use that (strip of paper) for the sky?

S17: *The student takes the paper and places it between the earth and the moon. And some nights you can see the whole thing. The student removes the paper. You might be able to see it (moon) because the sky won't be in front (**Alt_Other-Sky**).*

The student (S17) was explaining, while using material (a piece of paper) to represent her understanding, the cause of moon phases before the instructional intervention.

Alternative Fragments

Children whose responses were categorized as *Alternative Fragments* conceptual understanding included a subset or subsets of alternative conceptual understandings in their explanation of the cause of moon phases. A participant's responses categorized as alternative fragment included responses that were not clearly defined as being in any one type of conceptual understanding. Responses may include fragments from more than one conceptual model.

Before instruction four students (19%) held alternative fragments as their type of conceptual understandings. After the instructional period, only one student (4.7%) held alternative fragments to explain the cause of the moon's phases. An excerpt exemplifying this type of conceptual understanding follows.

- I: Show me the movements like they would really happen.
S14: *The student puts the models in the full moon position.*
I: So what does the moon look like right there?
S14: The full moon.
I: And then what happens?
S14: *The student rotates the earth model on its axis, while the sun and moon models remain in the same place. The pin that signifies our community is turned away from facing the moon. The moon gets skinnier (Alt_Rotation).*
I: ...Arrange the models so you would have a full moon like in this drawing. *The student is shown a drawing of a full moon.*
S14: *The student arranges the models in a full moon position with the pin on the earth model facing the moon model.*
I: This is what we call a new moon...Arrange the models so that we would see what is in the drawing.

- S14: *The student rotates the earth model so that the pin is facing away from the moon model and now is facing the sun model. The moon model remains in the same place. We can't see it. The moon is down and the sun is up (Alt_Rotation).*
- I: *Could we see this moon? The student is shown the drawing of the crescent moon.*
- S14: *Yes. Rotating the earth again...We could see only this piece.*
- I: *Why could we see only this piece?*
- S14: *Because the earth is blocking some of the sun (Alt_Eclipse).*

The student continues to describe the different phases by rotating the earth toward or away from the moon. The moon remains stationary in her explanation of the cause of moon phases. The student was categorized as holding an alternative fragment type of conceptual understanding because she included both the alternative rotation explanation and the alternative eclipse idea within her explanation.

No Conceptual Understanding

There was one student (4.7%) prior to the instructional intervention who was unable to explain her understandings about the cause of moon phases. On the post-assessment interviews, everyone held some type of understanding.

Results of the Types of Conceptual Change

Pre- and post-interviews were used to gather data about the participants' understanding of the cause of moon phases to answer research question number three. Data from the interviews were analyzed and used to determine each student's conceptual understanding of the cause of moon phases. The children were interviewed individually before and after the instruction. The interviews were videotaped. The

transcriptions of the students' responses were analyzed, coded, and classified to describe the individual's conceptual understanding of the cause of moon phases. Frequency counts were tabulated so that numerical comparisons between the pre- and post-assessments could be made.

The interview required the participant to explain what he/she thought caused the moon's phases and to use three dimensional (analogical) models to accompany their causal explanations. The data for question three are reported in Table 4.3.

Categories of Understanding	Pre-Instruction	Post-Instruction
Scientific Understanding	0	11
Scientific Understanding with Alternative Fragments	0	2
Scientific Fragment	0	1
Alternative with Scientific Fragment	5	1
Alternative	11	5
Alternative Fragment	4	1
No Conceptual Understanding	1	0

Table 4.3 Types of Conceptual Understanding for the Cause of Moon Phases

Before Instruction

Before instruction children were very likely to hold alternative conceptual understandings about the cause of moon phases. Prior to the instructional intervention the 21 participants most commonly held alternative understandings of the cause of moon phases. The results are summarized in Table 4.3. None of the children were able to articulate scientific explanations for the cause of moon phases. There were no students who held scientific understanding, scientific understanding with alternative

fragment, or scientific fragments of the cause of moon phases. Eleven (52.4%) children held alternative conceptual understandings of the cause of moon phases. Five (23.8) children held alternative conceptual understandings with one science fragment, while four children (19%) held alternative fragments, and one child (4.8%) held no conceptual understanding before instruction. **Children who held alternative conceptual understanding were likely to believe that the shadow of the earth or some other object was blocking the sun's light and causing the phases.** Five students reported on the pre-assessment interview and one on the post-assessment interview that the earth's shadow was blocking the sun's light from reaching the moon. In addition, one student thought the sky was blocking the moon, and another thought the clouds were blocking the moon's light. Other participants' responses coded as Alternative Conceptual Understanding included the heliocentric model, the geocentric model, the earth rotation model, Anthropomorphism, and distance of earth, moon, and sun.

After Instruction

After instruction more students were likely to hold scientific conceptual understandings of the cause of moon phases. More than half of the participants (14 students, or 66.7%) held a scientific understanding or some scientific understandings of the cause of moon phases. Only seven students (33.3%) held alternative understandings. Specifically 11 students (52.4%) held the scientific conceptual understanding, two participants (10%) held a scientific understanding with an alternative fragment, and one student (5%) held a scientific fragment for the cause of moon phases.

Cause of Moon Phase Summary

While having children hold a scientific understanding of the cause of moon phases was one instructional goal, moving students closer to an understanding was important. Even though not all of the students reached the ultimate goal, the findings suggest that many moved toward a more scientific understanding. Before the instructional intervention none of the 21 students held a scientific understanding, scientific understanding with alternative fragments, or scientific fragments. After the instructional intervention more students held a scientific understanding of the cause of moon phases.

In summary, before the instructional intervention the students' conceptual understanding of the cause of moon phases was mostly alternative and after the intervention the students' conceptual understandings were mostly scientific.

Qualitative Results for Shapes, Sequences, and Cause of Lunar Phases

In comparing children's responses on the pre-assessment and post-assessment tasks for all of the targeted moon concepts, it is evident that there was a change in understanding from alternative to more scientific. Table 4.4 provides data related to the shifts in children's scientific understanding in four areas: scientific moon phase drawings, the waning and waxing sequence drawings, both the scientific shapes and sequences moon drawings, and the scientific conceptual understanding for the cause of moon phases.

Targeted Moon Phase Concepts	Pre-Assessment (%)		Post-Assessment (%)		Gain (%)
Scientific moon phase drawings	0	(0%)	8	(38.1%)	38.10%
Scientific waning and waxing sequence drawings	0	(0%)	8	(38.1%)	38.10%
Both scientific phases and sequence drawings	0	(0%)	5	(23.8%)	23.80%
Scientific cause of moon phases interview responses	0	(0%)	11	(52.4%)	52.40%

Table 4.4 Participants' Responses Coded as Scientific

See Table 4.5 for a summary of the frequencies of children's pretest and posttest conceptual understandings. Note that the totals by category match those from Table 4.3 with the pretest and posttest totals for children's conceptual understanding about the cause of moon phases.

Also, see Figure 4.3 for the gains children made from pretest to posttest. Using a rubric (see Appendix G), children were scored from 0-10 points, depending upon the type of conceptual understanding each child expressed through modeling and interview comments. The gains were calculated by finding the difference between the pretest and posttest scores. For example, student (S 13), who had an alternative fragment conception on the pretest (1 point) and a scientific understanding on the posttest (10 points), received a gain score of 9. For student (S10), who held an alternative conception on the pretest (2 points) and an alternative with one scientific fragment on the posttest (3 points), the gain score was 1.

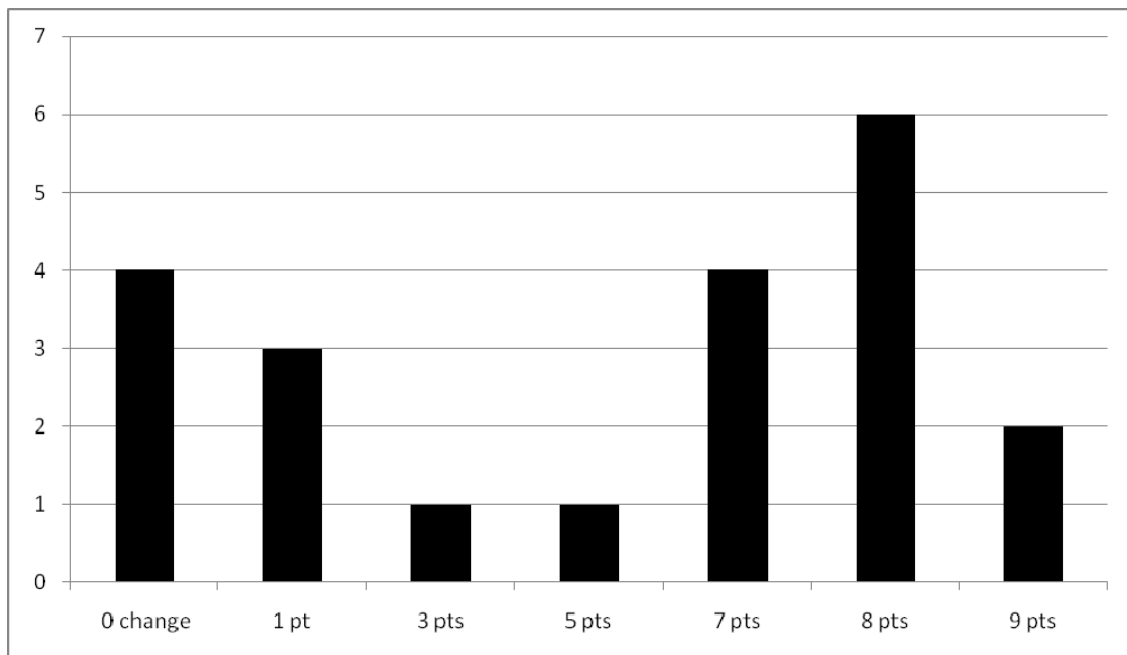


Figure 4.3. Students' Improvement Scores. The scores were computed by subtracting the pretest conceptual understanding score (see Appendix G for rubric) from the posttest conceptual understanding score.

Quantitative Results for Shapes, Sequences, and Cause of Lunar Phases

To support the qualitative comparisons, a nonparametric statistical test was used to examine the changes in conceptual understanding from alternative or scientific from pre- to the post-interview. Children's conceptual understandings were scored with a scoring rubric designed in a previous study (Trundle et al., under review). Children's pre- and post-interview scores were compared using the Wilcoxon Signed Ranks Test. Results indicated that significantly more children expressed , through modeling and interview comments, scientific understanding of the cause of moon phases from pretest to posttest ($Z=3.54$, $p = .0001$).

The McNemar test for two related samples was used to examine the numbers of children who changed in content knowledge of moon phase shapes from the pre- to the post-test based on their drawings. Results indicated that significantly more children drew scientific moon shapes on the posttest than on the pretest ($p=.016$). Results for the drawings of moon phase sequences were similar in that significantly more children drew scientific moon sequences on the posttest than on the pretest ($p= .008$). Also, significantly more children drew both scientific moon shapes and sequences on the posttest compared to the pretest ($p= .031$).

Summary of the Findings

There was a notable change in children's responses to when the moon can be observed. Before instruction most children reported that the moon can be observed most often at night. After instruction most children reported that the moon can be observed both sometimes during the day and sometimes at night.

Children's knowledge about the observable moon shapes changed during the study, as well. Prior to the instructional intervention fewer children were likely to include representative moon phase drawings, and children were likely to include at least one non-scientific moon phase in their drawings. Although more children were including representative moon shapes and those drawings were more scientific during the instructional intervention, none of the children included all eight representative moon phase shapes. There was a positive shift in the children's drawings of moon shapes after the instructional period. Children included more representative moon phase shapes in their drawings and eight children included all eight representative moon phase shapes in their drawings.

Children's ability to draw the moon's phases in a sequence improved over time. Although many children attempted to draw the waxing and waning moon sequences the majority of the drawings before instruction were coded as non-scientific. Post-assessment results were notably positive with more children able to demonstrate scientific knowledge of the regularly recurring pattern of moon phases. After instruction more than one-third of the students were able to draw both the waning and waxing moon sequence accurately.

Collectively the children demonstrated poor knowledge of observable moon shapes and sequences before instruction. Children did not include scientific shapes or sequence moon phases in their drawings before instruction, but five children drew both scientific shapes and sequences after instruction.

There was a positive change in children's ability to sort the eight representative moon phase cards when comparing pre- to post-assessment results. Before the

instructional intervention only a few children were able to organize the cards in the representative sequences, while after the instructional intervention more than half of the students were able to perform the task accurately.

Before instruction none of the children could articulate the scientific explanation related to the cause of moon phases. There were no students who held scientific understandings, scientific understandings with an alternative fragment, or scientific fragments of the cause of moon phases. After the instructional intervention there was a notable shift in children's understandings. More than half of the students held a scientific understanding or some scientific understandings of the cause of moon phases. While the instructional goal was to have children hold a scientific understanding of the cause of moon phases, moving toward the goal was notable progress with this age group.

The Wilcoxon Signed Ranks test results indicated that significantly more children expressed scientific understanding of the cause of moon phases on the post-assessment compared to the pre-assessment, while the McNemar test indicated that significantly more children were able to draw scientific moon phase shapes on the post-assessment compared to the pre-assessment. Similarly, the McNemar test indicated that significantly more children were able to draw scientifically waning and waxing moon sequences on the post-assessment compared to the pre-assessment. More children were able to draw both alternative shapes and sequences on the post-assessment than on the pre-assessment.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Introduction

The purpose of this mixed methods study was to describe, report, and interpret young children's understandings of targeted lunar concepts before and after implementing an inquiry-based, technology-enhanced instructional intervention designed to promote scientific understanding. Specifically, the lunar concepts included knowing when the moon could be observed, knowing the observable moon phases, understanding the regularity of moon phase sequences, and understanding the cause of moon phases. The children were twenty-one Primary students in a self-contained classroom within a suburban Midwestern school district. Throughout the guided inquiry the children collected and recorded lunar data, using *Starry Night* planetarium software and then analyzed their moon findings, guided by *Physics by Inquiry* (McDermott, 1996) inquiry-based activities. Data about the children's understandings were collected from semi-structured interviews, student drawings, and a card sorting activity before and after instruction. Students' lunar calendars and written responses, participant observer field notes, and videotaped class sessions also provided data throughout the study.

This chapter reviews the findings reported in chapter 4 and situates these findings within the context of previous teaching and learning research and specifically

examines the literature on lunar studies. This review is presented in five sections. The first section discusses the targeted lunar concepts outlined by the *National Science Education Standards* and the Ohio Academic content standards that impacted the frame of this study. The second section discusses the general summary of the present study and the specific assertions and findings related to children's understandings of the targeted concepts and the related literature. The third section explores the relevant role that inquiry, socio-cultural environment, and technology-enhanced investigations played in the study. The study's limitations will be presented in the fourth section. Finally, the implications of the present study's results for science education and recommendations for future research will be discussed in the fifth section of this chapter.

Lunar Concepts in the Standards

The *National Science Education Standards* (NRC, 1996) target understanding lunar concepts as part of scientific literacy. For this study, specific standards reflecting three levels of knowledge were explored. The very youngest children are expected to observe the moon both at night and during the day. For Grades K-4 children learn to *identify sequences of changes and look for patterns in the changes*. Both the very youngest children and the elementary-age children are expected to notice what can be observed in the sky from an earth-viewer perspective. These standards are focused on descriptions and observations, which are conceptually less demanding than what is expected of children in grades 5-8. In the Ohio Academic Content standards, children in Grade 5 should be able to explain that the moon orbits the Earth, and by Grade 8 students should be able to describe how the moon changes in predictable cycles. The

Benchmarks for Science Literacy (AAAS, 1993) suggest that children in Grades 6-8 examine the cause of moon phases, which is a more abstract spatial concept than observing and describing patterns of movement and changes in the shape of the moon over time.

As reviewed in chapter 2, most of the previous lunar research literature has been descriptive in nature (Baxter, 1989; Bisard et al., 1994; Dai & Capie, 1990; Schoon, 1995; Sharp, 1996; Trumper, 2001a, b) and provides evidence that across ages, populations, and varied levels of education people hold similar alternative conceptions about the lunar concepts. The descriptive studies are important in identifying commonly held alternative conceptions, but they do not identify strategies and instructional interventions that facilitate conceptual change. There are relatively few studies that examine effective instructional interventions used in elementary school science classrooms to promote scientific understandings of lunar concepts with younger students (Barnett & Morran, 2002; Stahly et al., 1999; Trundle et al., in review; Trundle et al., 2007a).

The Stahly et al. (1999) study focused on the conceptual understandings of four key informants within one third-grade classroom before and after instruction. The instruction consisted of the earth, sun, and moon relationships that determine the cause of lunar phases. Like the present study, Stahly and colleagues found some positive changes in children's understandings after the instructional period. Stahly et al. did not include inquiry activities, but instead used a textbook format, a more traditional approach, to present the scientific perspective related to the cause of lunar phases. There was no lunar data collecting and recording, as in the present study, and children

did not describe the lunar phases or the sequence of the lunar patterns. In another conceptual change study with 14 academically advanced Grade 5 students taking a self-selected science course, Barnett and Morran (2002) found some positive changes in understanding of the cause of moon phases and lunar and solar eclipses. The researchers used class discussion, three-dimensional models, and whole and small group activities. The activities were based on the Challenger Center's Space science curriculum, which did not appear to have addressed the National Science Education Standards for K-4 as in the present study.

Except for one study (Trundle et al., 2007a), no previous studies thoroughly investigated fourth-grade student learning in a specifically designed instructional environment. Trundle et al.'s study included a non-traditional, inquiry-based pedagogy relative to the *National Science Education Standards* and reported positive results with fourth-grade children. The present study used the same guided inquiry intervention with younger children than Trundle et al.'s sample. The present study also included a technology-enhanced data gathering method, unlike the Trundle et al. study, and focused on younger students.

By focusing on young children and exploring their conceptual understandings of lunar phenomena before and after instruction, using a pedagogy similar to that of Trundle et al. (2002, 2007a), the present study makes a contribution to the scientific literature on young children's understanding of lunar concepts, the importance of guided inquiry in the science classroom, and children's effective use of planetarium software to gather data.

Young Children's Lunar Concept Understandings

The group of participants included in this study range from 7 to 9 years of age. The heterogeneous group of children is multiage, and they were beginning to develop an understanding of their natural world in a formal academic arena. According to the literature, some conceptual understandings are expected to be naïve (Vosniadou & Brewer, 1992), because children construct intuitive knowledge about their world based on everyday experiences. As stated earlier, the concepts children hold may include a coherent set of ideas that may or may not be compatible with scientific knowledge. The researcher in this study was interested in the initial ideas children held related to the lunar phenomena outlined in this study. The present study examined the knowledge children held, how they interpret their ideas, and how those existing ideas stayed the same or changed conceptually (Trundle et al., in review; Trundle et al., 2007a). These concepts were framed in a theoretical context of mental models, including intuitive, synthetic, or scientific models (Vosniadou & Brewer, 1994), as discussed in chapter 2.

General findings

Not unexpectedly, many of the children in this study held alternative, non-scientific beliefs about the moon phases before the instructional intervention was introduced. Generally, drawings of both the moon's phases and the phase sequences, and the explanations children held for the cause of the moon's phases could be described as intuitive and synthetic. The children's ideas about the targeted lunar concepts were in a starting position and moved toward a more scientific understanding after instruction. In some cases, children's ideas moved toward a robust scientific

understanding after instruction. In the present study, the children's alternative understandings were consistent with the literature. Many of the children reported that the moon's phases were caused by a shadow being cast onto the moon by the earth or cloud (Baxter, 1989; Bisard et al., 1994; Schoon, 1995; Stahly et al., 1999; Trundle et al., 2002).

It was surprising that most children did not demonstrate knowledge of the moon's occasional presence in the daytime sky, considering that the national (NCR, 1996) and state science, the *Academic Content Standards* (Ohio Department of Education [ODE], 2003) documents suggest this phenomenon be introduced to our very youngest students. Generally, the children's responses to the pre-assessment interviews and tasks revealed poorly organized prior knowledge regarding lunar information.

However, it was noteworthy that the majority of the children after the instructional intervention held scientific knowledge about the moon's phases and the sequence of the moon's phases, as well as scientific understandings of the cause of phases. It was particularly interesting that children could articulate the scientific cause of moon phases, considering that this concept is abstract and difficult even for many adults to understand, as documented in the previous literature. Children's mental models of lunar knowledge evolved through guided inquiry events situated in an environment that included collaboration and the use of technology.

Finally, the findings after implementing the instructional intervention were dramatic, even for this age child. This study used *Physics by Inquiry* (McDermott, 1996) curriculum with *Starry Night* planetarium software to collect the lunar data.

Previous studies (Trundle et al., 2002, 2007a, 2007b), using *Physics by Inquiry*, have reported similar performance results across various age and experience ranges.

The next section provides a summary of the assertions and findings related to the present study.

Assertions and Discussion

Before the instruction most children held nonscientific understanding of when the moon can be observed, but after instruction 17 students (81%) responded that the moon can be observed sometimes at night and sometimes during the day. Before instruction only one child responded that the moon could sometimes be seen in the daytime sky. Interestingly this concept is listed as a benchmark in the Kindergarten curriculum in the *Academic Content Standards* (ODE, 2003) for Science in Ohio. Knowledge acquisition begins in infancy (Spelke, 1991) and continues through an individual's lifetime. By the time children begin their formal schooling they have already acquired a substantial amount of knowledge about their physical world based on everyday experiences. Observing the moon sometimes during the day would be part of that physical world knowledge one would think, however, the pre-assessment findings demonstrated the opposite.

During the study children found the moon in the daytime sky while collecting data on *Starry Night* and in natural observations on the playground. During the first week of lunar data collecting the children observed that the moon was visible in the daytime sky. After locating the information on the planetarium software, a student took one doubting student (S12) to the classroom window and pointed out the moon that was visible from our location during the day. Explicitly showing this student the moon

appeared to change her concept of when the moon could be observed, as evidenced in her post-assessment responses. This was an example of one child scaffolding another's understanding in an overt act that others witnessed. Through this type of support one child, and possibly others witnessing the event, was able to reach an understanding with assistance (Vygotsky, 1978).

The guided inquiry task of observation and recording lunar data appeared to support children's understandings. The change in understanding was demonstrated through the students' written and oral responses after the instructional intervention. After the instruction most of the students (17, or 81%) stated they could observe the moon during the day sometimes and at night sometimes, thus making change evident. The finding was not included in the previous studies related to young children's understanding of the lunar concepts.

Prior to instruction, all children included at least one alternative, non-scientific phase among their moon drawing. After instruction more children drew scientific moon phases, with 8 students (38.1%) drawing scientifically accurate representations of all eight moons. Before instruction children were asked to draw all of the moon shapes they expect or expected to see in the sky. Results from analyzing the pre-assessment drawings demonstrated that all of the children included a non-scientific moon phase in their drawings. Similar results were reported in Trundle et al. (2007a) with fourth-grade students, in Trundle et al. (in review) with almost all of the middle school students, and in Trundle and Bell (2006) with graduate students. In each of the studies students included at least one non-scientific moon shape in their drawings before instruction.

After instruction, more children drew scientific moon phases. There was an important change in the children's ability to draw scientific moon shapes. Prior to the instructional intervention none of the children were able to draw all eight moon phases with accuracy. After the instructional intervention, eight of the children (38.1%) drew all eight scientific phases, while one student included seven of the eight scientific moon phases. In sharp contrast to the pre-assessment findings, after instruction most shapes drawn were scientific (80.1%) and the number of moon shapes drawn had increased significantly. Similarly, Trundle et al. (in review) found dramatic post-instructional results with the eighth-grade participants drawing more scientifically accurate moon shapes. Trundle et al. (2007a) found that 93.4% of the fourth-grade students included scientific drawings, and the number of drawings increased markedly after instruction. As in the present study, the eighth-grade and fourth-grade studies included observing, recording, and sharing moon data throughout the nine-week lunar data collection period.

Considering that the children in the present study were younger, the results of the scientifically drawn moon phases were even more impressive. The carefully crafted instructional intervention focused the children's attention to the details of the moon's shape and led to these positive changes. Describing observable moon phases and identifying patterns of change in the moon's appearance were apparently not addressed in both the Barnett and Morran (2002) study and the Stahly et al. (1999) study.

The most commonly drawn moon phase was the full moon, with all 21 children including a scientific full moon phase in their drawings before, during, and after instruction. This was expected, since children were instructed to draw the full moon and

other moon phases. In addition to the full moon, the most common moon shape drawn was the crescent moon phase. This finding is consistent with Trundle et al.'s (2007a), Trundle et al.'s. (in review), and Trundle and Bell's (2006) findings. The full moon and crescent shape moons are represented often in children's literature and in the media, which may explain students' awareness and inclusion of the shape. Children may see the crescent moon shape in advertisements or in the children's literature they read.

Children drew scientifically accurate full moons, new moons, and quarter moons more often. For this age child, a full moon shape, a new moon shape, and a quarter moon shape were less difficult to draw. Small muscle (fine motor/physicality) coordination is not well developed in many children, so the "pointy" articulated tips of the crescent moon shape and bulging curves of the gibbous moon shape appeared difficult to execute. Although drawing the circular moon shape did not appear challenging, children demonstrated great difficulty filling in the illuminated portion of the specific moon shape they were drawing. Children used crayons and pencils to represent the illuminated moon and often colored outside the shape.

The gibbous and crescent shapes appeared to be the most difficult to draw. The moon phase drawn accurately least often was the gibbous moon phase. Many of the non-scientific gibbous moon phases resembled an eclipse. However, children appeared to be able to recognize the scientifically drawn gibbous and could talk about the shape as being "more than a half moon" or "less than a full moon".

The crescent appeared challenging to represent with many of the crescent phases either over- or under-articulated. The children repeatedly verbalized their frustrations either with their drawings or the drawings of others during lunar data collection times.

None of the children expressed scientific knowledge of both the waning and waxing pattern of moon phases before instruction. After instruction more children drew scientific representations of both the waning and waxing moon phase sequences (8 students, or 38.1%). Most children could draw a scientific waning sequence (12 students, or 57.1%) and many drew an accurate waxing sequence (10 students, or 47.6%).

Tasks 2 and 3 focused on the sequencing of the moon's waxing and waning phases. Most children knew that the moon phases appeared to change in a predictable sequence, but some children believed that the order of phases was random. Before instruction children were unable to draw the waxing and waning series scientifically. The finding on this task before the instructional intervention can be interpreted as reflecting children's lack of awareness of the moon's sequence of change. Trundle et al. (2007a) found similar results with fourth-grade students.

Children recorded nine weeks of lunar observations. These observations were recorded both in the student's moon journal and on the community calendars hanging in the room as visual references. Children met formally once each week to discuss lunar observations and recordings as a whole group. At this time attention was drawn by the participant observer to the moon's sequence of shapes. Often questions were asked by the participant observer to focus attention on shapes and sequences. For example, a question that was asked often was "Does the moon *appear* to be a getting bigger moon or a getting smaller moon?" Children were reminded by their peers and the participant observer that the moon does not change shape, only what we can see changes.

One student (S7) shared his experience with waxing in candle-making. His story appeared to help students discuss the shapes of the “growing” moon. Children referred to the appearance of a “getting bigger moon” as a waxing moon. This language parallel seemed to help children define the appearance of the moon waxing with scientific vocabulary.

The findings, both during and after the instructional intervention, indicated that many children were capable of changing their conceptual understanding of the sequence of moon phases. Most importantly, each child appeared to progress at a different pace, with eight children having scientific understanding of the moon’s sequence of phases and many having partial understanding at the conclusion of the study. Children grappled with understandings related to lunar patterns throughout the study. Partial understanding was evident before and after instruction. For example, before instruction eight of the nine students who drew non-scientific waning series of moon shapes drew waxing moons. Conversely, nine of the twelve drawing non-scientific waxing moon series drew a waning series of moons on the mid-assessment task. Although many children reported that the moon’s phases were in a sequence, they struggled to explain the pattern. After instruction the same anomaly appeared. Many of the students drawing the non-scientific series of moons commonly reversed the series by putting waning moons in a waxing series or waxing moons in a waning sequence. Trundle et al. (2007a) found similar results in their fourth-grade study with 14 of the 20 children who presented non-scientific representations, including waxing moon phases in a waning series and waning phases in a waxing sequence.

The task of drawing the sequence of moon phases was physically challenging for young children who have less developed fine motor skills. As stated earlier, children demonstrated difficulty with shading the illuminated portion of the moon using crayons and colored pencils. They often marked outside their drawings, making it difficult to interpret some of the shapes in their constructed lunar sequence.

Even though all of the students had agreed after the instructional intervention that the moon appears in a predictable sequence, some were unable to construct in two-dimensional drawings the scientific order of that sequence. Vosniadou (1994, 2002) refers to conceptual change as being gradual. Children in this study were confronted with science concepts that appeared radically different from their prior beliefs about moon phases. As the children recorded the lunar pattern daily after collecting visual data from *Starry Night*, some participants were unable to realize the scientific order of the waning and waxing moons.

Evidence of children's understanding related to the sequence of moon shapes in the present study is consistent with previous research (Trundle et al., 2002; Trundle et al., 2007a). In these studies positive gains were reported for scientific waning and waxing drawings after instruction with preservice teachers and fourth-grade students, respectively. Trundle et al. (in review) also found strongly improved post-instructional waning and waxing moon drawings with eighth-grade students.

This study's findings were more positive than those of Osborne et al. (1994). Osborne et al. found that only 20% of the older students (8- 11 years) and none of the younger students (5-7 years) were able to put the lunar phases in order after an intervention period that included lunar observations and models of the sun-earth-moon.

Before instruction most of the students were unable to arrange the lunar card drawings in a scientifically accurate series, but after the instruction the majority of students were able to arrange the cards in an accurate series.

Before instruction only four students (19%) were able to arrange the eight representative moon phase cards in a scientifically accurate pattern. After the instructional intervention more than half of the students were able to place the cards in a scientific sequence. The card sorting task was included in the interview protocol with the assumption that sorting shapes that were given to the participants would be easier or less cognitively demanding than drawing shapes in a sequence with no visual prompt. This aspect of the interview was particularly important with young children who have a range of fine motor abilities. In other words, the drawing task was assumed to be more physically and cognitively demanding. The results of the card sorting task were more positive than the drawing task. The results could have been limited by the data gathering process. Sorting cards was cognitively less demanding than drawing and ordering moon phase sequences. The task was used in previous studies with young students (Trundle et al. 2007a), but the findings were not reported.

None of the children were able to articulate accurate explanations for the cause of moon phases before instruction. After instruction many understood the cause of moon phases (11 students, or 52.4%). The findings before instruction were not surprising considering that research provides evidence that people hold alternative conceptual understandings about the cause of moon phases across ages, varied levels of training and populations (Barnett & Morran, 2002; Baxter, 1989; Broadstock, 1992; Schoon, 1995; Stahly et al., 1999; Trumper, 2001a; Trundle et al., 2002).

Understanding the cause of moon phases is considered complex and conceptually more demanding than knowing moon shapes and the sequence of phases. Both the National Research Council (1996) and the American Association for the Advancement of Science (1993) acknowledge the complexity of the lunar phase concepts. In fact the *National Science Education Standards* (NRC) suggests that the cause of moon phases be introduced in grades 5-8, and the *Benchmarks for Science Literacy* (AAAS) suggests that it be taught in grades 6-8.

As revealed in the pre-assessment interviews, most of the children (20, or 95.2%) held alternative conceptions related to the cause of lunar phases before the instructional intervention was introduced, while one student held no understanding. This finding is consistent with the results of other studies, including elementary through college students and preservice teachers (Dai & Capie, 1990; Schoon, 1995; Trundle et al., 2002, 2007a).

The most common alternative conception in this study was the eclipse or interference model, as described in chapter 2. Several of the children believed that the earth blocked the sun's light to the moon causing the moon's shape to change. One student attributed the change to clouds and one to the sky interfering with the moon's shape. These findings are consistent with those of other researchers (Baxter, 1989; Bisard et al., 1994; Dai & Capie, 1990; Schoon, 1995; Trundle et al., 2002). Brewer (2008) theorized that the eclipse (naïve) model is prevalent due to instruction related to the eclipses. Brewer stated that children "import the entire machinery of lunar eclipse and apply it to the phases," (p.71). It may be believed that the shadow from the earth cast on the moon moves slowly over one month's time to form a dark portion on the

moon that changes its apparent size. Many of the students used the eclipse model to explain the cause of phases. For example, Student 10 reported that the earth blocked the moon and caused the moon to appear different shapes. Another student in the present data set used the blocking argument to articulate his causal explanation. The clouds moved in front of the moon to cause the changes, he explained.

(S11): Clouds are blocking (the moon). You can still see it (the moon), but it is making part of it you can't see. Clouds are blocking it (the moon).
He explains the new moon phase. Clouds are over (the moon). Everything is blocking it, so you can't see the moon.

The children in the present study held other alternative conceptions related to the cause of moon phases before the instructional intervention, including the earth rotating on its axis, the heliocentric model, anthropomorphism, and distance between the earth, sun, and moon. One young student attributed the cause of the moon phases to moon holes letting out less light when the moon is tired and more light when it is not. Piaget described interviews with children holding anthropomorphist conceptions related to lunar phenomena. In Piaget's early studies (1929/ 1972) he described young children's thought about the existence of the moon as often being animistic, in which the child gives the object a life-like quality. This type of explanation was not included in other lunar studies, possibly because the comparison studies included older children than the present study.

Some children held multiple alternative conceptions to explain the causal relationship. One student indicated that the earth's rotation causes the moon to look differently. From our location on earth, according to this student, we see a different

moon than individuals in other locations. The same student felt that the earth sometimes blocks a portion of the sun causing the moon phase to appear less than full.

Following the inquiry-based instruction most children (66.7%) held partial or complete scientific understandings related to the cause of moon phases. For some children this conceptual change appeared to be complete revision in thinking from their initial ideas. For example, the student mentioned earlier described clouds obscuring the moon during the pre-assessment interview. He demonstrated how the clouds moved across the moon, using cotton and the three-dimensional models to explain the changes in the moon's appearance. This student, during the post-instructional interview, explained and demonstrated the cause of moon phases scientifically.

For others it was an integration of scientific ideas into an existing frame. Eleven students held scientific conceptual understanding, while two more students held scientific understanding with an alternative fragment and one held a scientific fragment conceptual understanding. The students holding scientific understanding with an alternative fragment and scientific fragments provided evidence of holding some scientific causal understanding. Using the same curriculum and format, Trundle and colleagues (in review) saw an even more dramatic change in understanding with eighth grade students making a 73% gain from pre- to post-instruction interviews. Barnett and Morran (2002) reported less of a change in their study with four students out of 14 (28.6%) demonstrating a scientifically sound understanding of the cause of lunar phases. In Stahly et al.'s (1999) study, which used a more traditional textbook approach, the four key informants showed some positive changes but "seemed to maintain some aspects of their original conceptions" (p.173). Holding onto the original

concepts which diverged from the scientific view demonstrates the resilience of their ideas.

Five children in the present study held an alternative understanding related to the cause of the moon's phases, while one student held alternative fragments conceptual understanding after the instruction. Vosniadou and Brewer (1992) found that children may, in reconciling their everyday understandings about the physical world with the scientific models, reinterpret the two models into a hybrid or synthetic model.

Relevant Factors

Guided inquiry

Emerging from the cognitive science research (Vosniadou et al., 2001), there is general agreement in the design of effective learning environments. The environment should engage students in active processing of skills and knowledge, and the learning environment should be situated in a social and cultural context. These designs were taken into consideration for the present study.

The instructional intervention, based on *Physics by Inquiry*, included activities that guided children through authentic data collection, observational data recording, and analysis tasks, as well as a psychomotor modeling activity. By the very nature of the instructional intervention, children were encouraged to actively use science investigative skills within a collaborative working environment. This instruction was not traditional in the sense that the teacher or textbook gave students the information related to the moon. Instead, the children actively found lunar data, shared their findings, recorded and tracked information, and tested their own thinking against

others' in a scaffolded investigation. Metz (2004) would contend that this type of inquiry was authentic without the "decomposition" of specific skills outlined by the standards. For example, the *National Science Education Standards*, she points out, parses the science process skills into individual components. In grades K-4 children are asked to only observe the sky, describe and find patterns of moon shapes. In this study, the guided inquiry approach encouraged children to assume responsibility, ask questions, find answers, challenge others' findings, test their own beliefs with limited restrictions, make sense of their findings, and, as a result, extend their learning. In this way, children constructed models of understanding, some scientific and some synthetic (Vosnaidou & Brewer, 1992).

Stahly and her colleagues (1999) investigated third-grade students' understandings about the cause of lunar phases. Traditional instructional materials included six textbook lessons, student 2-dimensional illustrations of the earth, sun, and moon, and the use of 3-dimensional models to explain the cause of phases. The researchers found some positive changes in the four key informants' conceptual understandings of the lunar phenomena, but thought the topic too complex for third-grade children. The researchers in that study found that after the instructional intervention was implemented some of the students continued to display non-scientific understandings. Stahly and her colleagues also stated that the traditional instructional approach, which did not include students' active involvement, may not have been the most effective method to use.

The present study used a more non-traditional approach in which young students were actively involved in enhancing their understandings of the lunar phenomena.

Students learning through guided inquiry in a supportive environment appear more likely to gain scientific knowledge related to the moon shapes and the regularity of moon phases, as well as the understanding of the cause of moon phases, than has been reported in studies using other methodologies.

Socio-cultural Environment

The classroom became a working laboratory with its members sharing practices, language, and knowledge. Small groups worked collaboratively to gather and record lunar data daily. Whole groups shared findings weekly and used this time as a forum to agree with or discount ideas, share new ways of finding data, check anomalies, plan next moves, predict next findings, and resolve problems with managing the tasks.

Collaboration allowed the children to share the work load both physically and cognitively. The children scaffolded learning for others by demonstrating, telling, and showing. The scaffolding events began as children navigated the software menu but went on as children grappled with the targeted lunar concepts. Peer scaffolding experiences continued throughout the study.

Through the discourse events, children needed to share their evidence-based reasoning clearly with support from the data collection. These events of “self explanation”, Vosniadou et al. (2001) suggested, are powerful mechanisms for promoting understanding and conceptual change. Initially children explained their thinking, their point of view, with little common understanding. As the study progressed, children began to develop a shared vocabulary until the scientific language was introduced. The participant observer shared alternative ideas that some students brought to the attention of the whole group, so they could be discussed and tested in the

milieu of science data and in a safe environment where all ideas were welcomed. The experientially-based activities provided students with opportunities to test, investigate, and talk about their existing understandings through both small and whole group scientific discourse events. Children negotiated meaning through these events.

The tools children used to guide the learning were the activities designed by McDermott (1996). The tasks were introduced by the participant observer but quickly taken over by the children. The children controlled their learning by talking with others, moving through the tasks with help or helping others, and testing their ideas against the lunar data that they were collecting.

Technology-Enhanced Tasks

Previous research has demonstrated the value of computer simulations in the science classroom. Akpan and Andre (2000) found their students performed significantly better on a performance test after using a program to simulate the testing situation. Monaghan and Clement (2000) concluded that computer simulations had a positive effect on logical reasoning and inquiry.

For this study children used planetarium software to collect lunar data. Although the children did not directly experience these phenomena, the planetarium software enabled them to manipulate environments virtually, to set times, and to track the moon's dynamics easily and safely within their classroom.

Songer (2007) suggested that using technology to support scientific inquiry is an effective way to gather, analyze, and interpret data. Technology also allows the user to explore and manipulate environments and objects in order to develop an understanding of concepts like lunar phases. Bell and Trundle (2008) reported significant gains in

achievement when preservice teachers used *Starry Night* to make lunar observations, when compared to preservice teachers using natural observation and those using a combination of natural observation and the computer simulation.

After one brief introduction to the features of the software, the children began to collect lunar data in their small groups. More experienced students organized groups and provided support, facilitating less able students. This scaffolding by students proved beneficial for the entire group. If children had a question or a need related to the software, they did not wait for my help, but requested help within their group. Because there were five computers with the software and five groups, the students could gather data in a timely fashion. At times children challenged the findings. They knew to return to the software to resolve an anomaly. Children were able to check their data effectively and quickly.

In whole group discussions children reported shortcuts and new features they found while using *Starry Night*. Most wrote positive remarks in their moon journals or shared in whole group about using the software. In this way the software was a motivational tool to support learning about the lunar phenomena.

Children's data collection was continuous. The children collected nine weeks of moon observation data in five weeks, while using the software. Data collection was not hampered by weather conditions, physical objects like buildings obstructing the view, or time of day the moon was visible. In summary, using the planetarium software appeared to support the data collection process for this study.

Limitations

The study included various limitations that will be reviewed here. The participants for this study were selected because of availability. The students were from one self-contained Primary classroom. Besides the limited number of student participants (21), the majority of this population came from middle-class homes, resulting in little socioeconomic diversity within the group of participants. Many of the students had computers at home and so were comfortable with the medium. Due to the nonrandom nature of the sampling, the results are of limited generalizability.

The research design allowed the primary researcher to be in contact with the participants throughout the day over an extended period of time. The researcher was an *insider* which can be both beneficial and problematic. Classroom-based research can be a powerful professional development tool for the teacher/researcher. Planning and observing student work allowed the researcher to gather information, analyze and reflect on instructional practices that were effective and modify those practices that were not appropriate. Classroom-based research also can be difficult to manage. Since teacher goals and researcher goals can be conflicting, the researcher needed to be aware of her role in the study. For example, as a teacher the researcher wanted to clarify confusions, but instead led children to test their ideas and predictions. As a teacher, the researcher wanted to expose the children to multiple resources, i.e. literature, speakers, fieldtrips, and videos, but remained consistent and followed the planned methodology.

The pre-interview format and the pre-task activities could have had an impact on student performance on the post-interview and the post-tasks, positively influencing the

data collected for analysis. The pre-interview and pre-tasks may have sparked some participants to think more critically about the topic. Participants may have conducted independent studies at school or asked parents about information relating to the lunar study. Students may have attended more critically to pertinent information in the media and on television. External influences could not be controlled, measured, or their effect interpreted for the present study.

The three-dimensional models representing the sun, the moon, and the earth used in this study were not to scale for obvious reasons. Inaccuracies in scale may have caused misunderstandings related to size and relative distances of the astronomical bodies, the sun, the earth, and the moon. However, Trundle et al. (2002) found that the models used during pre- and post-interviews did not appear to make a difference in the post results.

Young Elementary Students' Conceptual Understandings of Lunar Phases and Cause of Phases

The purpose of this study was to describe and report the responses of Primary children during a moon study project before and after implementing instructional interventions that may promote scientific understandings.

Young children appeared to be capable of greater conceptual understanding of moon sequences and moon phases when taught through guided inquiry. In this study it appeared that the guided inquiry approach to learning the targeted lunar concepts made a positive impact for children. Guided inquiry instruction with metacognitive and affective factors is likely to be successful (Sinatra & Pintrich, 2003; Trundle et al.,

2002, 2007a; Vosniadou, 2003). Prior to interacting with this non-traditional instruction, described in chapter 3, this group of young children's conceptual understanding of the moon shapes, the moon phase sequences, and the cause of the moon phases was limited. Most children did not know that the moon could sometimes be observed during the day, and they drew many pictures of moons that were considered non-scientific. Before the instruction most of the children were unable to draw a waning and a waxing moon sequence, and none of the children had a scientific conception of what causes the moon phases.

After the guided inquiry instruction that was implemented during the study, the children's conceptual understanding greatly improved for all of the targeted moon concepts. The findings were more positive than was anticipated considering the complexity of the lunar concepts. Knowing and drawing the waning and waxing moon phases is an elementary concept, and understanding the cause of moon phases is suggested for grade 5-8 students. The *American Association for the Advancement of Science* (AAAS, 1993) document states that the study of the cause of moon phases should occur in Grades 6-8.

Collaborative learning is viable with young children. This particular approach to learning gives students a strong sense of ownership in their work. Most of the tasks were managed by the children working in small groups, locating and recording lunar data. They communicated within the small and whole group, sharing, justifying, disputing, and checking findings and explanations. This approach seemed engaging for children because of their control of the tasks. Furthermore, this approach appeared to make children more metacognitively aware of inconsistencies in their conceptual

understandings. Metaconceptual awareness, self-regulation, motivation to engage in the work, and critical thinking are key factors in learning, identified by both cognitive development research and science education research (Vosniadou, 2003).

Young children can interact productively with content-rich software. Using the computer simulation software made data collection very manageable and efficient. For example, the students were able to consistently observe the moon from the same location each day. Unlike natural observation, children were able to observe and gather nine weeks of lunar data regardless of weather conditions. Having a more complete data base, children were able to see the phases over time without any missing information.

Rich learning environments support the development of conceptual information. The classroom served as a microcosm of investigators gathering, sharing and making sense of the data each day. The situational and cultural contexts have become more important when trying to understand how to facilitate conceptual change for the individual (Vosniadou et al., 2001).

This study extends the work of Trundle and her colleagues (2007a) in which it was reported that fourth-grade children were able to understand and explain lunar phases, the sequence of lunar phases, and the cause of the lunar phases after observing and collecting lunar data and exploring cause of lunar phases using an instructional intervention. The present study included the same instructional intervention, while using planetarium software to gather the data with a younger population. To date the curriculum and the technology were found to be highly successful with preservice teachers. However, the current study combined both with a much younger population.

Finally, the study is relevant for science teachers and science teacher educators. The present study provides an example of how instruction that is designed for teacher education can be transferred successfully from teacher professional development to classroom instruction for young children. This study also demonstrates how an experienced teacher, who was a novice with the curriculum and technology, can support learning within an elementary classroom.

Recommendations for Further Research

This study examined the conceptual understanding of young elementary students before and after an instructional intervention related to lunar phenomena. As a result of this project, questions emerged that could be addressed by further research.

The students in this study exhibited a variety of alternative conceptions related to lunar phenomena before the instructional intervention. It is important to uncover alternative conceptions that students hold in other science domains. Driver (1981) emphasized the importance of recognizing students' preconceived notions related to science understandings. Further research is needed in other targeted concepts within the *National Science Education Standards* (NRC, 1996) for elementary students, so that common alternative conceptions held by students can be identified and addressed with effective instructional techniques and strategies. Replication of this type of study is needed in other science domains for this age group.

The results for the present study were gathered, analyzed, and reported immediately concluding the lunar activities. The findings showed positive conceptual changes in young children's scientific understandings about the moon's phases, the

sequence of phases, and the cause of lunar phases. It is possible the results might not be durable for this population. In order to report that conceptual change remained in effect over time, delayed-post interviews could be conducted to check retention. Although the instructional intervention included strategies, like being reflective about the lunar findings, revisiting the lunar data, and grappling with anomalies in the data, which supported a deeper processing of the lunar data, some children may hold only partial understandings of the targeted lunar concepts or may hold a tentative scientific understanding. Having newly acquired scientific conceptual understandings be durable and established is important for effective learning, since future concepts will be built upon these existing lunar conceptions.

The results from the present study should not be seen as generalizable to the population of young children in general. While the sampling and the methodology used in the present study allowed for the implementation of the instructional intervention in a suburban science classroom within a heterogeneous setting, the results are not generalizable to young children within all public school classrooms. In order to extend the generalizability of these findings, it would be useful to replicate the study in different settings with different populations. For example the present study could be replicated in an urban or a rural classroom. The class size was small in this study. Therefore, this instructional intervention will need to be implemented with larger groups and more groups of students in order to strengthen the data claims.

The exploratory environment in this study appeared to influence the conceptual changes that occurred as children observed, collected, and analyzed the lunar data. Guided inquiry within the science classroom is becoming more widely adopted as a

teaching and learning strategy. In order to strengthen the data claims, this study could be replicated using other science domains in an inquiry context, in which the students actively gather and analyze data, using investigative skills.

These are only a few of the lines of research that the science education community needs to address in order to develop a more scientifically literate society beginning with our very youngest population.

Lunar concepts are recommended by the National Science Education Standards (NRC, 1996) for inclusion in science curriculum for Grades K-4. Students at these grade levels are expected to study patterns of movement and observable shape changes in the moon. The standards suggest children find evidence of the changes, as well as determine causal explanations for the phenomena in Grades 5-8.

In the present study young children explored the concepts of observable shapes, sequence of changes in the moon's appearance, and the cause of the moon's phases within a heterogeneous science classroom. The study focused on students' conceptual understandings and how they changed, while the students used guided inquiry and technology enhanced strategies to gather and analyzed lunar data. Both qualitative and quantitative data indicated that young children held alternative conceptions or no conceptions before the instructional intervention. After completing the guided inquiry-based, technology enhanced instruction, a majority of participants' conceptual understandings of the moon's apparent shapes, the sequence of the phases, and the cause of the moon's phases had changed. More children held scientific understandings related to the lunar phenomena. The instructional intervention used in the current study

appears to be a potentially effective method to teach science within the elementary classroom.

In conclusion this study demonstrated that a well-designed guided inquiry-based, technology-enhanced intervention offers promise to promote conceptual change with young children.

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APPENDIX A

MOON CALENDARS FOR MARCH, APRIL, AND MAY 2008

Appendix A Moon Calendars for March, April, and May 2008

T		W	T	F	S	1
30 M Time _____ Direction _____ Angle _____	31 Time _____ Direction _____ Angle _____					 Time _____ Direction _____ Angle _____
2 Time _____ Direction _____ Angle _____	3 Time _____ Direction _____ Angle _____	4 Time _____ Direction _____ Angle _____	5 Time _____ Direction _____ Angle _____	6 Time _____ Direction _____ Angle _____	7 Time _____ Direction _____ Angle _____	8 Time _____ Direction _____ Angle _____
9 Time _____ Direction _____ Angle _____	10 Time _____ Direction _____ Angle _____	11 Time _____ Direction _____ Angle _____	12 Time _____ Direction _____ Angle _____	13 Time _____ Direction _____ Angle _____	14 Time _____ Direction _____ Angle _____	15 Time _____ Direction _____ Angle _____
16 Time _____ Direction _____ Angle _____	17 Time _____ Direction _____ Angle _____	18 Time _____ Direction _____ Angle _____	19 Time _____ Direction _____ Angle _____	20 Time _____ Direction _____ Angle _____	21 Time _____ Direction _____ Angle _____	22 Time _____ Direction _____ Angle _____
23 Time _____ Direction _____ Angle _____	24 Time _____ Direction _____ Angle _____	25 Time _____ Direction _____ Angle _____	26 Time _____ Direction _____ Angle _____	27 Time _____ Direction _____ Angle _____	28 Time _____ Direction _____ Angle _____	29 Time _____ Direction _____ Angle _____

APPENDIX B
MOON JOURNAL
Task A: Patterns

Appendix B Moon Journal (Adapted from McDermott, *Physics by Inquiry*, 1996)

Name _____

Moon Instruction

During the weeks of moon observations you and your classmates have been collection observational lunar data. By putting all of these observations together we may be able to find a more precise appearance of the moon.

Please use your moon data to answer the following questions.

Research Question: What properties of the moon can be observed?

Task A Patterns

- 1. Look at your moon data. Are there any repeating patterns in the shape of the moon?**

- 2. If so, describe the pattern.**

- 3. Does the moon change quickly from one shape to another or is the change gradual?**

Patterns (Continued)

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APPENDIX B

MOON JOURNAL

Task B: Length of the Cycle

Name _____

Research Question: How long does the moon cycle last?

Task B

Length of the Cycle

1. Use your moon data calendar. Start at the beginning of your moon observations and number the first day “1”.
2. Number the following days in sequence (the second day is “2”). Include all of the days in which you collected data.
3. Choose a day on which the moon has a distinctive shape. Record the shape on the first row on the table below.
4. As carefully as you can, find the days on which the same shape occurred. Record the day numbers in the columns next to the shape.
5. Repeat steps 3 and 4 for a different shape. Continue until you have at least 4 shapes on your table.
6. Find the number of days between the return of the same shape. Is there about the same number of days between observations of that moon shape?
7. If so, about how much time passes before the identified shape reappears?
8. Is the interval of days about the same for all of the repeated shapes in the table?

Shape of the moon	Day Number	Day Number	Day Number

APPENDIX B

MOON JOURNAL

Task C: Sequencing Shapes

Name _____

Research Question: Do moon phases occur in a pattern? Are moon phases predictable?

Task C Sequencing Shapes

1. The drawings below show several moon phases. **Number each drawing** to show these phases in the **same order as you observed** them while collecting observational moon data.
2. **Cut each drawing** and glue or tape them in the same order that you observed them.
3. After completing **Task D**, the students will be able to **label each phase with a scientific label** (We will do the labeling together).

APPENDIX B

MOON JOURNAL

Task D: New Concepts and Scientific Labels

Name _____

Task D New Concepts and Scientific Labels

Moon Phases

New Moon

Waxing

Waning

Synodic period

Crescent

Quarter moon

First quarter moon

Third quarter moon

Gibbous

Full moon

APPENDIX B

MOON JOURNAL

Task E: Modeling Moon Phases

Name _____

Research Question: What causes Moon phases?

Task E Modeling Moon Phases

1. Darken a room and place a bright, exposed light bulb at eye level.
2. Hold a Styrofoam ball in front of you. The bulb represents the sun, the ball represents the moon, and your head is the Earth.
3. Move the ball around your head and note the appearance of the lit portion of the ball. Notice that the lit portion changes in a way that looks like the moon phases.
4. **How much of the moon is lit at any one time?**

5. **Can you reproduce all of the phases in the correct order using the Styrofoam ball and light bulb?**

6. **If so, should you move the ball clockwise or counterclockwise around your head?**

7. **Think about what you have observed. How can you explain the cause of the moon phases? Talk with your friends about it.**

8. **How can you test your theory? Test it out.**

APPENDIX C
STUDENT INTERVIEW PROTOCOL

Appendix C: Student Interview Protocol

Statements made to the student are in bold print.

Sequence of the Interview:

Introduction

Interview

Drawings

Models

Card Sort

Introduction:

Thank the student for participating.

The purpose of my research project is to help me become a better teacher.

I want to know how to teach moon phases effectively. As far as this interview, there are no right or wrong answers. I just want to understand what you know about moon phases. Your answers do not have anything to do with your science progress reports.

During the interview, I will be asking questions and you will give me your thoughts. Your answers will be videotaped and audio=taped. For some of your answers you will be asked to use models to help explain. Do you have any questions?

Interview:

Drawings: Moon Phases/ Shapes and Sequence Interview Questions (See Drawing Sheet in Appendix D1 and D2).

Task 1:

You probably have noticed that the moon does not always look the same.

Sometimes we have what we call a full moon, and at other times the moon is not full. The different appearances of the moon are called moon phases. Over the next weeks we will be making daily moon observations. Before you begin the observations, tell me all of the moon phases that you predict you will see. In the space below please draw a full moon and all other moon phases you predict that you will see during your observations. Label the full moon.

Task 2:

Do you think that the moon phases will appear in a predictable sequence or pattern? (Circle one) If the student answers affirmatively that he/she will see the moon phases in a predictable sequence or pattern, go on to Task 3. If not, move to Task 4.

Task 3:

If you thought that you would see the moon phases in a predictable sequence or pattern, please draw the moon phases in the sequence you expect to observe them.

Cause of Moon Phase Interview Questions (See Cause of Lunar Phases Coding Sheet Appendix F):

Task 4:

4A: You probably have noticed that the moon does not always look the same. For example, sometimes we can see what we call a “full moon” and at other times the moon is not full. What do you think causes the phases of the moon?

4B: Probe to get the student to explain what he/she thinks causes the phases of the moon to appear to change. (For example, **explain to me how something could block the moon to cause the phases. What could be blocking the moon? Explain how that happens.**)

Task 5: Cause of Moon Phases using models and drawings (Appendix F)

5A: Provide the student with the models of the sun, Earth, and moon. **These models of the sun, the Earth, and the moon are only representative. They are, of course, not to scale and they will not be the correct distance from each other. I want you to use the models while you are explaining to me what causes the moon phases to change.** If the student says clouds, use a piece of cotton to represent the cloud.

5B: (Drawing provided to show what the full moon looks like from Earth. Orange areas on the moon cards represent our perception of the moon on Earth at that phase). **Take the model and arrange it so that we would see a full moon. Why would the moon appear like this drawing?**

5C: (Drawing provided to show what the new moon phase looks like on Earth.) **Now arrange the models so that we would have a new moon phase. Why would the moon appear like this drawing?**

5D: (Drawing provided to show what the crescent moon phase looks like. Show the drawing.) **Could we see a moon that looks like this? If so, arrange the models so that we would be able to see a moon that looks like this drawing. Why would the moon appear like this drawing? If not, why not?**

5E: (Drawing provided to show what the gibbous phase looks like.) **Could we see a moon that looks like this? If so, arrange the model so that we would be able to see**

a moon that looks like this drawing. Why would the moon appear like this drawing? If not, why not?

5F: (Drawing provided to show what the “false gibbous” phases looks like.) **Could we see a moon that looks like this? If so, arrange the model so that we would be able to see a moon that looks like this drawing. Why would the moon appear like this drawing? If not, why not?**

5G: **Use the models to show what happens when the moon goes through one complete cycle of phases.**

5H: (Place the model components so that the phase of the moon is approximately at the first quarter phase.) **Look how the model is arranged now. Could the sun, Earth and moon be arranged like this? If not, why not? Is yes, suppose that you were here (point to a location facing the moon).With a clear skies what would you see when you looked at the moon? Draw what you would observe on this sheet. Why would the moon look like that?**

Task 6: Card Sort interview Questions (See Appendix G for Card Sorting pictures):
I want you to put these 8 drawings in the order you predict to see them.

APPENDIX D 1

MOON PHASE SHAPES AND SEQUENCES DRAWING SHEET

(Pre-instructional)

Appendix D (1): Moon Phase Shapes and Sequences Drawing Sheet
(Pre-instructional Intervention Assessment)

Name _____

1. You probably have noticed that the moon does not always look the same. Sometime we have what we call a full moon, and at other times the moon is not full. The different appearances of the moon are called moon phases. Over the next weeks we will be making daily moon observations. Before we begin observing the moon closely, please predict the appearance of all of the moon phases you will see. In the space below please draw a full moon and all other moon phases you predict to see during our future observations. Label the full moon.

2. Do you think that the moon phases will appear in a predictable sequence or pattern?
(Circle one)

Yes

No

3. If you predicted that you think the moon phases will appear in a predictable sequence or pattern, please draw the moon phases in the sequence you expect to observe them.

APPENDIX D 2

MOON PHASE SHAPES AND SEQUENCES DRAWING SHEET

(Mid- and Post-instructional)

Appendix D2: Moon Phases Shapes and Sequences Drawing Sheet
(Mid- and Post-instructional Intervention Assessment)

Name _____

1. You probably have noticed that the moon does not always look the same. Sometimes we have what is called a full moon, and at other times the moon is not full. The different appearances of the moon are called moon phases. Over the last weeks we have been making daily moon observations. Please record the appearance of all of the moon phases you saw during that time. In the space below please draw a full moon and all other moon phases you saw during your observations. Please label the full moon.

2. Based on your observations, do you think the moon phases appeared in a predictable sequence or pattern? (Circle one)

Yes

No

3. If you thought the moon phases appeared in a predictable sequence or pattern, please draw the moon phases in the sequence you observed.

APPENDIX E

CODING SHEET – MOON SHAPES AND PATTERNS

(Drawings)

Appendix E: Coding Sheet – Moon Shapes and Patterns (Drawings)

Researcher **H** **S** **T**

Name _____ Pre Mid Post

Shapes of moon	Sci	Alt	Label	Notes
Full moon				
Waning gibbous				
Third quarter				
Waning crescent				
New				
Waxing crescent				
First quarter				
Waxing gibbous				

Sequence Yes No

<i>Sequencing</i>	<i>Sci</i>	<i>Alt</i>	<i>Label</i>	<i>Notes</i>	
Moon wanes					
Moon waxes					
Phases included:	Sci	Alt	Label	Order	Notes
Full moon					
Waning gibbous					
Third quarter					
Waning crescent					
New					
Waxing crescent					
First quarter					
Waxing gibbous					

Trundle, K.C., Atwood, R.K., & Christopher, J.E. (2002). Preservice elementary teachers' conceptions of moon phases before and after instruction. *Journal of Research in Science Teaching*, 39(7), 633-658.

APPENDIX F

CODING SHEET FOR CAUSES OF LUNAR PHASES

Appendix F: Coding Sheet for Causes of Lunar Phases*

Type of Conceptual Understanding _____ Student # _____

Researcher **H S T**

Moon Study: pre post

4A and B What do you think causes the phases of the moon? Probe to get the student to **explain**.

SciOrb	SciHaf	SciSee	SciEMS	AltEcl	AltRot	AltHel	AltClo	AltFrg	AltOth	NoCU	Inc

5A Use these models to explain to me, and show me while you are explaining what you think causes the phases of the moon.

SciOrb	SciHaf	SciSee	SciEMS	AltEcl	AltRot	AltHel	AltClo	AltFrg	AltOth	NoCU	Inc

5B (Drawing provided to **show a representation of the full moon phase**. Orange areas represent what we see of the moon from Lexington at that moon phase.) Take these models and **arrange them so that we would see a full moon** in Lexington. **Why** would the moon appear like this drawing?

SciOrb	SciHaf	SciSee	SciEMS	AltEcl	AltRot	AltHel	AltClo	AltFrg	AltOth	NoCU	Inc

5C (Drawing provided to **show a representation of the new moon phase**.) Now **arrange them so that we would have a new moon**. **Why** would the moon appear like this drawing?

SciOrb	SciHaf	SciSee	SciEMS	AltEcl	AltRot	AltHel	AltClo	AltFrg	AltOth	NoCU	Inc

5D (Drawing provided to **show a representation of the crescent moon**. Show the drawing) **Could we see a moon that looks like this?** If so, arrange the models so that we would be able to see a moon that looks like this drawing. Why would the moon appear like this drawing? If not, why not? **YES NO**

SciOrb	SciHaf	SciSee	SciEMS	AltEcl	AltRot	AltHel	AltClo	AltFrg	AltOth	NoCU	Inc

5E (Drawing provided to **show a representation of the gibbous phase.**) **Could we see a moon that looks like this?** If so, arrange the models so that we would be able to see a moon that looks like this drawing. Why would the moon appear like this drawing? If not, why not? **YES NO**

SciOrb	SciHaf	SciSee	SciEMS	AltEcl	AltRot	AltHel	AltClo	AltFrg	AltOth	NoCU	Inc

5F (Drawing provided to **show a representation of the “false gibbous” phase.**) **Could we see a moon that looks like this?** If so, arrange the models so that we would be able to see a moon that looks like this drawing. Why would the moon appear like this drawing? If not, why not? **YES NO**

SciOrb	SciHaf	SciSee	SciEMS	AltEcl	AltRot	AltHel	AltClo	AltFrg	AltOth	NoCU	Inc

5G **Use the models to show me what happens as the moon goes through one complete cycle of phases.**

SciOrb	SciHaf	SciSee	SciEMS	AltEcl	AltRot	AltHel	AltClo	AltFrg	AltOth	NoCU	Inc

5H **(Place the models so that the phase of the moon is approximately at the first quarter phase).** Look how the models are arranged now. **Could the sun, earth and moon be arranged like this?** If not, why not? If yes, suppose that this straight pin is located to indicate where you are. With a very clear sky, **what would you see** when you looked at the moon if the sun, earth, and moon were in this arrangement? **Draw what you would see on this sheet.** **Why** would the moon appear like your drawing?

YES NO

SciOrb	SciHaf	SciSee	SciEMS	AltEcl	AltRot	AltHel	AltClo	AltFrg	AltOth	NoCU	Inc

*Trundle, K.C., Atwood, R.K., & Christopher, J.E. (2002). Preservice elementary teachers' conceptions of moon phases before and after instruction. *Journal in Science Teaching*, 39(7), 633-658.

APPENDIX G

SCORING RUBRIC FOR LUNAR CONCEPTS INTERVIEW

Scoring Rubric for Lunar Concepts Interview

Scientific:	Participant's conceptual understanding exhibits all element of scientific understanding without exhibiting alternative conception.
10 Points	Includes all elements of scientific understanding.
Scientific fragment:	Participant's conceptual understanding does not exhibit an alternative mental model, but fails to include all elements of scientific understanding.
9 Points	Missing one element of scientific understanding.
8 Points	Missing two elements of scientific understanding.
7 Points	Missing three elements of scientific understanding.
Scientific with alternative Fragment:	Participant exhibit all <u>four</u> elements of scientific understanding along with an alternative mental model.
6 Points	Includes all elements of scientific understanding with an alternative mental model.
Alternative with Scientific fragments:	Participant's conceptual understanding exhibits an alternative mental model, but also includes some elements of scientific understanding.
5 Points	Includes an alternative mental model, but also contains three elements of scientific understanding.
4 Points	Includes an alternative mental model, but also contains two elements of scientific understanding.
3 Points	Includes an alternative mental model, but also contains one element of scientific understanding.
Alternative:	Participant' conceptual understanding exhibits no elements of scientific understanding and includes a single mental model.
2 Points	Includes a single alternative mental model without any elements of scientific understanding.
Alternative fragments:	Participant' conceptual understanding exhibits two or more alternative mental models. Conceptual understanding may or may not exhibit some elements of scientific understanding.
1 Points	Includes two or more alternative mental models.
No conceptual Understanding:	Participant exhibits no conceptual understanding.
0 Points	Participant exhibits no conceptual understanding.

Sackes, M. & Trundle, K. (2009)