

THE COMPARATIVE EFFECTS OF A COMPUTER-BASED INTERACTIVE  
SIMULATION DURING STRUCTURED, GUIDED, AND STUDENT-DIRECTED  
INQUIRY ON STUDENTS' MENTAL MODELS OF THE DAY/NIGHT CYCLE

A Dissertation

by

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## ABSTRACT

This study compared middle school (i.e., fifth, sixth and seventh grade) students' mental models of the day/night cycle before and after implementation of three inquiry-based treatments. The three treatments were classified as 1) structured inquiry, 2) guided inquiry, and 3) student-directed inquiry. All three treatments used *Starry Night Middle School* interactive simulation software to investigate the phenomenon of the day/night cycle. Additionally, all three treatments were based on two researcher-developed lessons using *Starry Night Middle School*.

The participants were 145 fifth, sixth, and seventh grade students who were purposively selected from a public school in a U.S. state. For the purpose of this study, the students remained in their classrooms. There were three classrooms per grade level. Those classrooms were randomly assigned to one of the three treatments.

Students' scores on a pretest, immediate posttest, and delayed posttest were analyzed. Students from a purposive sample were interviewed after the pretest, immediate posttest, and delayed posttest to clarify student mental models of the day/night cycle. The students were chosen based upon their score on the multiple-choice test. Seven of the selected students were in the Structured Inquiry group. Eleven of the selected students were in the Guided Inquiry group. Five of the selected students were in the Student-directed Inquiry group.

First, the comparative effects of Structured Inquiry, Guided Inquiry, and Student-directed Inquiry on middle school students' mental models of the day/night cycle immediately and three months following the intervention revealed no statistical difference among the three treatments. Time, however, appeared to have a significant negative effect on students' mental models of the day/night cycle. Second, inquiry groups did not differ significantly in their mental models. Third, there was no interaction between starting mental model and the type of inquiry. The major findings demonstrate that all three treatments promote learning, but that no one treatment is more effective than another.

## DEDICATION

This dissertation is dedicated to my parents, Howard and Maureen; my mother-in-law, Gwen; my father-in-law, Danny; my husband, Thomas; and my daughter, Katelyn

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# CHAPTER I

## INTRODUCTION

### *Introduction*

Astronomy concepts are found within the standards of all 50 states and the District of Columbia, the National Science Core Standards, and the AAAS core curriculum benchmarks. Three National Science Core Standards for K-4 address

Astronomy concepts:

- I) “The Sun, Moon, stars, clouds, birds and airplanes all have properties, locations, and movements that can be observed and described” (National Research Council, 1996, p.134).
- II) “The Sun provides the light and heat necessary to maintain the temperature of the Earth” (National Research Council, 1996, p.134).
- III) “Objects in the sky have patterns of movement. The Sun, for example, appears to move across the sky in the same way every day, but its path changes slowly over the seasons. The Moon moves across the sky on a daily basis much like the Sun. The observable shape of the Moon changes from day to day in a cycle that lasts about a month” (National Research Council, 1996, p.134).

Since these are K-4 concepts, we would think that the students should hold scientific mental models of these concepts by the time they reach middle school. However, research indicates that many students hold alternative conceptions about the earth and its relation to other heavenly bodies that do not agree with the scientific conceptions. One of the most publicized examples of such research comes from the Harvard-Smithsonian Center for Astrophysics’ Project STAR. In their video, *A Private Universe* (Pyramid Film & Video, 1988), Harvard graduates, still in their robes, were asked about the cause of the seasons and other earth-position questions. Results revealed common misconceptions among most of these highly educated men and women. The

video then takes the viewer into a ninth grade classroom where several students are interviewed about their understanding of seasons. One student, identified by the teacher as incredibly bright, is interviewed over time while the researcher tries to change her ideas. This demonstrated how difficult it is to change students' misconceptions even one-on-one.

Vosniadou and Brewer (1992, 1994) conducted experiments investigating elementary school students' conceptual knowledge about the Earth and the day/night cycle. Their findings indicated that students' mental models fell into three categories: initial mental models, synthetic mental models, and scientific mental models. Initial mental models are constrained by misconceptions. Synthetic mental models are formed when students attempt to assimilate their initial mental model with the scientifically correct model. Scientific mental models agree with the scientifically correct model.

Since students need to correct their initial and synthetic mental models, the immediate concerns of the classroom teacher are: 1) to determine if misconceptions are present in their student population; 2) to help students recognize the need for changing their mental models; and 3) to help them make appropriate changes to their mental models. Changing mental models from initial and synthetic to scientific requires conceptual change and improved conceptual understanding. Although many studies have examined how classroom instruction affects students' conceptual understandings, few studies have studied changing students' initial and synthetic mental models into scientific ones (Diakidoy & Kendeou, 2001; Hayes, Goodhew, Heit, & Gillan, 2003; Sharp & Kuerbis, 2006).

Since inquiry-based learning is an active learning approach focusing on questioning, critical thinking, and problem solving, it can be used to challenge students' misconceptions and, therefore, correct their mental models (Modell, Michael, & Wenderoth, 2005). Inquiry is "a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; posing answers, explanations, and predications; and communicating the results" (National Research Council, 1996, p. 26). In grades 5-8, students should be able to:

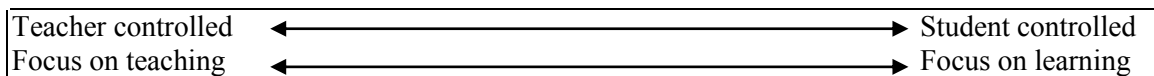
- "Identify questions that can be answered through scientific investigations;
- Design and conduct a scientific investigation;
- Use appropriate tools and techniques to gather, analyze, and interpret data;
- Develop descriptions, explanations, predictions, and models using evidence;
- Think critically and logically to make the relationships between evidence and explanations;
- Recognize and analyze alternative explanations and predications;
- Communicate scientific procedures and explanations;
- Use mathematics in all aspects of scientific inquiry" (National Research Council, 2000, p. 19).

The National Research Council (2000) states that inquiry-based learning can vary in the amount of structure, guidance, and coaching the teacher provides for the students. The amount of guidance, structure, and coaching provided by the teacher should vary depending on the skills and needs of the students. Similarly, Bonnstetter's (1998) inquiry

teaching continuum extends from teacher-directed, traditional hands-on to student research (See Table 1.1). It is interesting to note that, according to the National Research Council, students in today's classrooms rarely have the opportunities to ask and pursue their own questions. Therefore, they need opportunities to develop advanced inquiry skills.

Table 1.1  
*Continuum of teacher-directed to student-directed inquiry (Bonnstetter, 1998)*

	Traditional hands-on	Structured	Guided	Student directed	Student research
Topic	Teacher	Teacher	Teacher	Teacher	Teacher/student
Question	Teacher	Teacher	Teacher	Teacher/student	Student
Materials	Teacher	Teacher	Teacher	Student	Student
Procedures/ Design	Teacher	Teacher	Teacher/student	Student	Student
Results/ Analysis	Teacher	Teacher/Student	Student	Student	Student
Conclusions	Teacher	Student	Student	Student	Student



Few studies have compared the effects of types of inquiry-based learning with each other across grade levels (Scallon, 2006; Yager, 2005). Scallon (2006) compared the use of guided inquiry and authentic student research with eighth graders. Yager

(2005) compared how structured inquiry, guided inquiry, and full inquiry (open inquiry) affected 32 teachers' performances in terms of questioning and other classroom strategies. However, no prominent studies compare the effects of structured inquiry, guided inquiry, and open inquiry across fifth, sixth, seventh, and eighth grade students' mental models. Since crucial astronomy concepts are often misunderstood, research in this area could fill an important gap.

Simulation software allows “students to conduct simulated experiments with complex underlying models that they could not conduct in reality because of lack of time and equipment” (Chinn & Malhotra, 2002, p. 208). *Starry Night Middle School* (Imaginova Corp., 2005) is software that simulates astronomy concepts and is currently utilized in classrooms. Many studies have examined how the use of computer simulations affects students' conceptual understandings and the findings indicate that the use of computer simulations is effective in promoting scientific conceptions. (Bell & Trundle, 2006, 2008; Gazit, Yair & Chen, 2005; Trundle & Bell, 2005, 2010). Computer simulations can also be used to effect conceptual change (Windschitl & Andre, 1998). However, few studies have specifically examined how interactive simulation software affects students' mental models differentially according to age, developmental level, or grade (Kangassalo, 1993, 1994, 1997, 1999).

### *Problem Statement*

Researchers need to extend the mental models research into explorations of how student's mental models are formed and changed. Inquiry-based learning, with its focus on questioning, critical thinking, and problem solving, should be an effective method for



changing students' mental models. Educators need more information on whether students at different middle grade levels improve their mental models with less or more guided inquiry. Combining each of the three levels of inquiry-based learning with interactive simulation software in a study can help fill a gap in the literature.

#### *Purpose Statement*

The purpose of this study was to compare fifth, sixth and seventh grade students' mental models of the day/night cycle before and after the implementation of 1) student-directed inquiry activities, 2) guided inquiry activities, and 3) structured inquiry activities using interactive simulation software.

#### *Research Questions*

1. What are the comparative effects of inquiry types on middle school students' mental models of the day/night cycle immediately following the inquiry intervention and three months later?
2. What mental models (e.g. initial, lower synthetic, upper synthetic and scientific) do middle school students hold (a) prior to, (b) immediately after, and (c) three months after interventions using one of three inquiry types?
3. What interaction effect occurs between starting mental model, and inquiry type?

#### *Definitions*

*Inquiry-based learning:* Inquiry-based learning is a student-centered, active learning approach focusing on questioning, critical thinking, and problem solving with varying levels of teacher and student control. Inquiry-based learning can vary in the amount of structure, guidance, and coaching the teacher provides for the students. The effects of

three types of inquiry-based learning (student-directed, guided, and structured) are being compared.

*Student-directed inquiry:* In student-directed inquiry, the teacher provides the topic. The students and teacher select the questions to be investigated. The students and teacher design the experiment together. The students collect the data, analyze it, and form their own conclusions. Of the three types of inquiry being investigated, student-directed inquiry provides the students with the greatest amount of control. Student-directed inquiry is also called full inquiry and open inquiry (Bonnstetter, 1998).

*Guided inquiry:* In guided inquiry, the teacher provides the topic, the questions to be investigated, and the materials. The students and teacher design the experiment together. The students collect the data, analyze it, and form their own conclusions. Guided instruction divides the control equally between the teacher and students (Bonnstetter, 1998).

*Structured Inquiry:* In structured inquiry, the teacher provides the topic, the questions to be investigated, the materials, and the design of the experiment. The students collect the data, analyze it, and form their own conclusions. Structured inquiry provides the teacher with the greatest amount of control (Bonnstetter, 1998).

*Misconception:* A misconception is an understanding of a concept or principle that is not consistent with generally accepted views or interpretations of that concept (Modell, Michael & Wenderoth, 2005); the terms alternative conception, alternative framework, preconception, intuition, naïve theory and presupposition are also used. I am using the

term misconception because it is the term most used by articles in science education research journals.

*Mental models:* Mental models are representations in the mind of real or imaginary situations. They can be constructed from perception, imagination, or the comprehension of discourse. They underlie visual images, but they can also be abstract, representing situations that cannot be visualized. They are “a dynamic structure which is created on the spot for the purpose of answering questions, solving problems, or dealing with other situations” (Vosniadou & Brewer, 1992, p. 543). They refer to people’s personal knowledge.

*Initial mental models:* Initial mental models are constrained by presuppositions and misconceptions. A child who holds an initial mental model of the day/night cycle might think that the Earth is flat and stationary and is supported by something like dirt and rocks. If the child thinks the Sun is stationary then night might be explained by something covering the Sun or by the Sun turning off. If the child thinks the Sun moves then night might be explained by the Sun moving behind something like a mountain or that the Sun moves far away. Answer choices that followed from the use of an initial mental model were coded as a one. Students scoring between 14 and 16 were, therefore, coded as initial (See Appendix C).

*Synthetic mental models:* Synthetic mental models are formed when students attempt to assimilate their initial mental model with the scientifically correct model. A child who holds a synthetic mental model of the day/night cycle might understand that the Earth is spherical but also think that it is stationary. This child might explain that night occurs

when the Sun moves to the other side of the Earth. Answer choices that followed from the use of a synthetic mental model were coded as a two. Synthetic mental models can be divided into lower and upper synthetic (Plummer, Wasko & Slagle, 2011) (See Appendix C).

*Lower synthetic mental models:* Students scoring 17 through 29 were coded as lower synthetic. Lower synthetic mental models demonstrate less sophistication and limited coherence with scientific concepts in students' explanations (Plummer, Wasko & Slagle, 2011).

*Upper synthetic mental models:* Students scoring 30 through 40 were coded as upper synthetic. Upper synthetic mental models demonstrate increased sophistication in students' explanations (Plummer, Wasko & Slagle, 2011).

*Scientific mental models:* Scientific mental models are the culturally and scientifically accepted views. A child who holds a scientific mental model of the day/night cycle would understand that the Earth is spherical, rotates on its axis and revolves around the Sun. Answer choices that followed from the use of a scientific mental model were coded as a three. Students scoring 41 through 42 were coded as scientific. They indicate that scientifically correct responses were correctly selected (See Appendix C).

*Computer-based, interactive simulation:* According to Chinn and Malhotra (2002), simulations allow students to design experiments and gather data. Simulations have the additional advantage that the student is required to inquire into the event presented, to alter values of the parameters, to initiate processes, to probe conditions, and to observe the results of these actions. Students can interpret the underlying scientific conceptions

of the simulation, compare them with their own conceptions, formulate and test hypotheses, and reconcile any discrepancy between their ideas and the observations in the simulation (Zacharia & Anderson, 2003).

## CHAPTER II

### LITERATURE REVIEW

#### *Introduction*

The first chapter of this dissertation described the potential of using inquiry-based learning and computer simulation software as an effective method for changing students' mental models. Figure 2.1 shows the research that influenced this study.



*Figure 2.1.* Research influencing this study

### *Research on Mental Models*

Johnson-Laird's (1983) theory of mental models is one of the most influential theories to be formulated in cognitive psychology. His theory of mental models seeks to provide a general explanation of human thought. At the core of this theory is the assertion that humans represent the world they are interacting with through mental models. People must hold a working model of a phenomenon in their minds in order to understand a real-world phenomenon.

Gilbert and Boulter (2000) identified several key features to help researchers pinpoint and characterize the mental models used by individuals. First, mental models are generative. They are used by people to construct predictions and new ideas. This implies that "using mental models means going beyond the level of description to predict and explain" (Gilbert & Boulter, 2000, p.105). Second, they involve implicit knowledge. Individuals are not entirely aware of every component of their mental models. In addition, they are not completely aware of how they make use of their mental models.

A third key feature of mental models is that they can be synthetic. In other words, they do not represent every possible interpretation of the target concept. Synthetic models show the influence of the culturally accepted, scientific information about a target concept. People attempt to form a blend of their perspective and that of the scientific world. Lastly, mental models are also constrained by world-views. People will create and use mental models that conform to the general belief systems they hold.

### *Research on Mental Models in Astronomy*

Taylor, Barker, and Jones (2003) argue that building mental models is a fundamental skill in astronomy education. Astronomers have always used both mental models and physical models to understand phenomena and to explain their knowledge to others. For example, people have attempted to understand the place of Earth within the universe by using a series of mental models that began with a flat Earth on a sea enclosed within a solid celestial firmament, moved to Ptolemy's geocentric view and then Copernicus' concentric spheres.

Research has found that initial, synthetic, and scientific mental models are generated from and constrained by underlying conceptual structures (Samarapungavan, Vosniadou, & Brewer, 1996; Vosniadou & Brewer, 1992, 1994; Vosniadou, Skopeliti, & Ikospentaki, 2004, 2005). In a series of studies, Vosniadou and her colleagues identified five synthetic models of the Earth: the rectangular earth, the disk earth, the dual earth, the hollow sphere, and the flattened sphere. Nussbaum and Novak (1976) and Nussbaum (1979) found similar models, which they referred to as concepts or notions. Jones, Lynch, and Reesink (1987) also investigated the shape of the Earth, Moon, and Sun as well as the size and spatial model. Like Nussbaum and Novak (1976) and Nussbaum (1979), they found similar models, which they referred to as conceptions.

All of these studies used a structured interview pattern patterned on Piaget's clinical interview technique. The interview technique was developed in order to reveal children's version of the Earth concept. It was noted during the development process that "visual props were apt to provide the child with some cues that would interfere with the



spontaneity and authenticity of his natural thinking (thereby risking the validity of the interview interpretation)” (Nussbaum & Novak, 1976, p. 537). The researchers decided to start the interview with a set of questions without any visual model of the Earth.

Research has been conducted challenging some of their findings (e.g. Frede, et al, 2011; Nobes et al, 2003; Nobes & Panagiotaki, 2009; Panagiotaki, Nobes, & Potton, 2009; Schoultz, Saljo, & Wyndham, 2001; Siegal, Butterworth, & Newcombe, 2004). Schoultz et al (2001) critically scrutinized a number of studies’ findings about the difficulties children have in conceptualizing phenomena such as the shape of the earth. They challenged the idea that how an individual responds in the interview used by Vosniadou and her colleagues is a reflection of conceptual content in the mind of that individual.

Vosniadou, Skopeliti, and Ikospentaki (2004, 2005) responded to the criticisms of Nobes et al (2003), Schoultz et al (2001), and Siegal et al (2004). Vosniadou, Skopeliti, and Ikospentaki (2004) found that the open and forced-choice methods of questioning produced different results. The open method of questioning replicated the earlier findings of Vosniadou and Brewer (1992, 1994), Samarapungavan, Vosniadou and Brewer (1996), and Diakidoy, Vosniadou and Hawks (1997). They found that 80-85%, a great majority, of the children gave responses consistent with a small number of internally consistent mental models of the earth. Out of 48 possible response combinations, the researchers hypothesized that they would obtain only six. Five of those six hypothesized response combinations were obtained.

In contrast, the forced-choice method of questioning produced more scientifically correct responses. Vosniadou, Skopeliti, and Ikospentaki (2004) believed that some of the responses in the forced-choice questioning method were false positive responses, which may account for some of the increase in the positive responses. The other reason was that the forced-choice questioning method was mainly a recognition task because the children are reminded of the culturally accepted, scientifically correct answers. The forced-choice questioning method produced noticeably fewer internally consistent responses, even though the same criteria were used for measuring consistency in the two methods.

Panagiotaki, Nobes, and Potton (2009) investigated the claims of Vosniadou and Brewer (1992) that children have naïve mental models of the Earth. Two groups of 6 and 7 year olds' responses were compared. The first group (18 boys and 24 girls) was tested using the mental model theorists' original drawing task while the second group (46 boys and 39 girls) was tested using "a new version in which the same instructions and questions were rephrased to minimize ambiguity and, thus, possible misinterpretation" (Panagiotaki, Nobes, & Potton, 2009, p.52). They found that the new version elicited significantly higher proportions of scientific pictures and answers than the original version did. Also, the proportion of children who were classified as having nonscientific mental models was three times greater when the original version was used. Only 7% of the children in the new version had initial or synthetic mental models.

In another recent study, Bryce and Blown (2006) conducted longitudinal studies, which investigated the cultural mediation of children's thinking about the Earth. They

critically investigated past and present clinical interview methods in order to enhance their own technique. Interview, the authors believed, represented the only method for probing students' conceptual structures in a way that minimized culturally mediated constraints from interviewer/researcher bias. They found that in order to determine children's concepts of the shape of the Earth at the deepest level of conceptual organization the interview instrument must be tuned to that level. One way to effect this attunement, they suggest, was to avoid concrete models of possible Earth shapes. This supported the methodology of Vosniadou and her colleagues.

They also point out that "researchers who focused on teaching the scientific concept of a spherical Earth may design their research instrument in such a way that neither the intermediate cultural level nor the deeper intuitive level of conceptual structure is probed" (Bryce & Blown, 2006, p. 1143). Therefore, the introduction of a single model, like a globe, in the early stages of an interview is discouraged because it denies children the opportunity to construct their cosmologies from their own experience. According to the authors, this may explain why Schoultz et al (2001)'s findings contradicted those of Vosniadou and her colleagues.

### *Misconceptions Research*

Science education research, both nationally and internationally, has shown that students do not always accurately learn scientific information (Barrier, 2010; Odom & Barrow, 2007; Osborne & Freyberg, 1985; Talanquer, 2002; Wandersee, Mintzes, & Novak, 1994). One major reason is that students already possess their own conceptions based on their experiences and these conceptions differ in many ways from the accepted

views of science. These alternative explanations are seldom challenged in the science that students are taught at school.

Research into students' conceptions about astronomical phenomena has been investigated for more than 50 years (LoPresto & Murrell, 2011; Danaia & McKinnon, 2007; Haupt, 1948; Kuethe, 1963; Novak, 1979; Nussbaum & Novak, 1976; Sneider & Pulos, 1983; Stahly, Krockover, & Shepardson, 1999; Trundle, Atwood, & Christopher, 2004; Trundle, Atwood, & Christopher, 2006). Students' conceptions that are alternative to the accepted scientific beliefs have been labeled as misconceptions, preconceptions, children's science, alternative frameworks, nonscientific views, erroneous notions, private versions of science, synthetic mental models, unfounded beliefs, and naïve notions (Finegold & Pundak, 1990; Sneider & Ohadi, 1998; Vosniadou, 1991; Vosniadou & Brewer, 1992, 1994; Wandersee, Mintzes, & Novak, 1994) by various researchers.

Identifying students' misconceptions is an important part of classroom practice for teachers. Students "display misconceptions when they apply their mental models to a problem and reach an inappropriate answer" (Modell, Michael, & Wenderoth, 2005, p. 22). Teachers cannot correct students' mental models. But they can guide students to recognize that their mental models lead to incorrect conclusions. However, misconceptions can be very robust and, therefore, hard to correct.

Philips (1991, p.22) listed common misconceptions about space. In fourth through sixth grade, the misconceptions are:

- the Earth is round like a pancake;
- people see because light brightens things; and

- people do not live on Earth because it is in the sky.

In fourth grade through ninth grade students, the misconceptions are:

- people live on the flat middle of a sphere;
- there is a definite up and down in space;
- seasons are caused by the Earth's distance from the Sun;
- phases of the Moon are caused by a shadow from the Earth;
- different countries see different phases of the Moon on the same day;
- the Moon goes around the Earth in a single day;
- the Moon makes light the same way the Sun does;
- the Sun is directly overhead at noon;
- the amount of daylight increases each day of summer;
- the Earth's revolution around the Sun causes day and night;
- day and night are caused by the Sun going around the Earth;
- planets cannot be seen with the naked eye; and
- planets appear in the sky in the same place every night.

Vosniadou and Brewer (1992), Vosniadou and Brewer (1994), Bell and Trundle (2006), Bell and Trundle (2008), Barrier (2010), Danaia and McKinnon (2007), Finegold and Pundak (1990), Finegold and Pundak (1991), LoPresto and Murrell (2011), and Trundle, Atwood, and Christopher (2007a) found similar misconceptions.

Many strategies have been offered to correct students' misconceptions. Abdi (2006) asserted that misconceptions can be confronted through hands-on and minds-on activities. Teachers should ask inquiry-type questions to determine students' misconceptions. Teachers should use discrepant events to help eliminate students' naive thinking and promote critical thinking. Finally, teachers should make connections between students' prior knowledge and the new science concepts.

Similarly, Minstrell and Smith (1983) suggested certain guidelines that teachers could follow. First, teachers should ask children for their ideas. Second, they should "listen respectfully to the ideas the students express and to their explanations of why

these ideas make sense to them, and encourage the other students to do so as well” (Minstrell & Smith, 1983, p. 33). Finally, they should “encourage the children to discuss and resolve discrepancies between their initial predictions or explanations and the new evidence they discover or experience” (Minstrell & Smith, 1983, p. 33).

### *Research on How Classroom Instruction Changes Mental Models*

Several researchers have studied how classroom instruction changes students’ mental models (Diakidoy & Kendeou, 2001; Hayes, Goodhew, Heit, & Gillan, 2003; Kangassalo, 1993, 1994, 1997, 1999; Taylor, Barker, and Jones, 2003). Diakidoy and Kendeou (2001) compared the effectiveness of two instructional approaches in the acquisition of the basic astronomy concepts, the shape of the earth and the day/night cycle. The control group received standard instruction following the objectives and the guidelines of the *Cyprus national curriculum* and the *Geography teacher’s manual*. The experimental group received modified instruction that considered preconceptions and focused on explanations that maximize the plausibility of scientific conceptions. Their results found that the experimental instruction, which considered preconceptions and focused on explanations that maximize the plausibility of scientific conceptions, had a strong positive effect on learning and understanding.

Hayes, Goodhew, Heit, and Gillan (2003) examined how information diversity can be used to promote change in children’s mental models of the earth’s shape. The structured interview process used by the researchers to access the children’s mental models before and after the training was adapted from Vosniadou & Brewer (1992). The researchers produced three 6-minute instructional videos, which were used in the three

training conditions. Children in the single-belief conditions (training conditions 1 and 2) watched four video episodes focusing on either the relative size of the earth or the effects of gravity. Children in the dual-belief condition (training condition 3) watched two video episodes focusing on the size of the earth and two video episodes focusing on the effects of gravity. The control group had traditional classroom instruction without the videos.

Hayes, et al (2003) found that children in the single- and dual-belief training conditions showed a greater increase in correct responses from pre-test to post-test than children in the control group. However, their intervention had only modest success in changing children's mental models. Two-thirds of the students in the three training conditions maintained nonspherical models at the post-test. The pattern of change, nonetheless, was consistent with their predictions. A significant shift toward use of spherical models was found in the dual-belief condition relative to the control, but not in the single-belief condition. The researchers also found that the dual-belief condition was advantaged relative to the other groups when the change from less complex to more sophisticated nonspherical models was examined.

Taylor, Barker, and Jones (2003) investigated a mental-model building strategy where students were given the opportunity to generate, critique, and refine their mental models about the Sun-Earth-Moon system. The teaching intervention consisted of eleven 1 hour astronomy lessons presented to 33 students in grades 7-8. The lessons were divided into four phases: focus on the mental models; mental model building and critiquing; using the scientists' mental model to solve problems; and reflection. In phase 1, the students stated and compared their prior mental models within their group and

within the class. In phase 2, the students designed, conducted and interpreted activities to find out which mental model they prefer, using the scientists' model testing process. In phase 3, the students used the preferred scientists' mental model to solve problems that are novel to them. In phase 4, the students reported their findings to the rest of the class, which then critically evaluated the solutions and explanations. Prior to the intervention, only 48% of the students held the scientific mental model that the Moon orbits the Earth which orbits the Sun. In both the post-survey and the post-post-survey, 90% of the students held the scientific mental model.

Trundle, Atwood, Christopher, and Sackes (2010) studied the effect of guided-inquiry-based instruction on eighth grade students' conceptual understanding of lunar concepts. The instruction, taken from *Physics by Inquiry*, was divided into three parts where students 1) gathered, recorded, and shared moon data based on their observations, 2) analyzed their moon data, and 3) modeled the cause of moon phases. Prior to the instruction, 95% of the students included nonscientific phases in their moon drawings, 85% of the students' knowledge of the regularly recurring pattern of moon phases was nonscientific, and only 15% of the students drew both waxing and waning errorless scientific sequences. None were able to draw scientific phases, scientific waning and waxing sequences, or provide a scientific explanation of the cause of moon phases. After the instruction, 85% of students drew only scientific moon phases, 50% drew only errorless scientific moon phase sequences, and 73% were able to provide a scientific explanation of the cause of moon phases. According to Trundle, et al. (2010) "gains this



strong from pre instruction to postinstruction are rare in the conceptual change literature” (p. 469).

### *Computer Simulations Research*

Research into how computer simulation affects students’ mental models is limited (Kangassalo, 1993, 1994, 1997, 1999). However, research into how computer simulation affects conceptual change is more extensive (Bell & Trundle, 2006, 2008; Evagorou, Ttoffi, & Constantinou, 2001; Gazit, Yair, & Chen, 2005; Zacharia & Anderson, 2003). Since conceptual change is required to correct students’ mental models, that extensive research can be extended by investigating the effect of interactive simulation software on changing students’ mental models from initial to synthetic to scientific.

In multiple studies, Kangassalo (1993, 1994, and 1997) investigated how the independent use of a pictorial computer simulation, PICCO, affected children’s conceptual models of a selected natural phenomenon. According to her, a conceptual model is a mental construct that makes it possible to think about a phenomenon, to describe it, and to explain and predict the events of the phenomenon. The term is often used synonymously with mental model. The selected natural phenomenon was “the variations of sunlight and heat of the sun as experienced on the earth related to the positions of the earth and sun in space” (Kangassalo, 1993, p. 605). In each study, she found that the children’s conceptual models of the phenomenon were developed and built upon during their exploration to varying degrees. However, all that development was toward the scientifically correct model.

Plummer, Wasko, and Slagle (2011) studied third grade students' explanations of the daily patterns of apparent motion of the Sun, Moon, and stars. The students were interviewed before and after participating in school-based astronomy curricula. Prior to the instruction, the students were asked to observe and record the locations of the Sun and Moon during the morning and evening as well as the Moon's appearance for two to three days. During the instruction, the computer-based astronomy program, *Stellarium*, was used to observe the motion of the Sun and Moon over time. The researchers also had the students use kinesthetic descriptions to physically model the Sun's apparent motion, the Earth's rotation, and the apparent motion of the stars. In addition, the students drew pictures to illustrate the concepts they were learning. Students also used physical models to test possible reasons for the apparent motion of the Sun and Moon. Plummer, Wasko, and Slagle (2011) found that most students improved, and many reached the scientific level on their scale. However, the remaining students were hindered from moving to more sophisticated levels of understanding by a few challenges.

Windschitl (2000) described how simulations, modeling software, and data analysis tools provide young children with rich intellectual environments for inquiry when used with proper instruction. He defined simulation as "models, created by experts, that learners explore in order to conceptually organize their own mental models" (Windschitl, 2000, p. 87). Simulations enable students to investigate systems in the natural world within a virtual environment, to experiment, and to begin to synthesize their mental models of the underlying phenomena. Students can also change variables that would be impossible to change or unrealistic to change in the natural world.

When selecting simulations for instruction, Windschitl (2000) recommended considering the type of environment they present and the type of decisions they evoke from the student. Not all types of simulations are suited for the inquiry process. Process or strategic simulations are generally suitable for the practice of inquiry skills. This form of simulations allows students to manipulate variables to effect changes in related variables and, therefore, is intellectually engaging.

There are several issues with using simulations to support inquiry. First, students may not be willing to make the necessary effort to use simulations in a mindful, productive way. Second, students may learn to value only questions that can be solved through quantitative analysis. They may not realize that inquiry can also be non-numeric, non-discrete, historical, personal, political, and qualitative. Third, simulations alone cannot prompt the development of inquiry skills.

Windschitl (2000) made four general recommendations for educators. First, teachers should embed the simulation within constructivist curricular approaches. Second, teachers should allow students to conduct inquiry with real materials as well. Third, teachers should monitor how students are making sense of their inquiry and scaffold as necessary. Lastly, teachers should give students adequate time.

Though their study does not measure change in students' mental models, Evagorou, Ttoffi, and Constantinou (2001) tested their interactive simulation to evaluate student understanding of moon phase formation. They found that the use of simulation software has a number of advantages over traditional paper and pencil tests. First, more realistic renditions of the phenomenon can be achieved in simulation format. Second,

time-dependent phenomena cannot be projected on paper. Third, the use of software allows the evaluation to focus on more productive aspects of student understanding. Lastly, they found that minor advantages emerged from the opportunity to use color and the more realistic renderings of the simulation.

Zacharia & Anderson (2003) investigated the effects of interactive computer-based simulations presented prior to inquiry-based laboratory experiments on students' conceptual understanding of mechanics, waves/optics, and thermal physics. Their results indicated that the use of the simulations improved the students' ability to make acceptable predictions and explanations of the phenomena in the experiments. It also fostered a significant conceptual change in the physics content areas that were studied.

Bell and Trundle (2006) studied preservice elementary school teachers' conceptions of moon shape and the cause of moon phases before and after the use of the computer simulation software *Starry Night* in conjunction with actual observations of the moon. Their study drew heavily from recent literature that reflects a conceptual development perspective (Carey, 1985; Vosniadou, 1991; 1999; 2003; Vosniadou & Brewer, 1994; Vosniadou, Skopeliti, & Ikospentaki, 2004). Participants were divided into two groups (Group 1, n=50; Group 2, n=61). Both groups used *Starry Night* to gather observational data about the moon and completed the same inquiry instruction targeting moon phase concepts. The first group spent nine weeks using *Starry Night* to gather all the data while the second group spent three weeks gathering moon data from observations then six weeks gathering data using *Starry Night*.

Pre-instruction results demonstrated that “neither group of preservice teachers was able to accurately draw scientific moon shapes, accurately represent the waxing and waning phase sequences, or explain the cause of moon phases” (Bell & Trundle, 2006, p. 18). Post-test results indicated that both approaches were effective in promoting scientific understandings. However, the achievement gains of group 1 were greater than those of group 2. The authors gave three possible explanations for the results. First, using *Starry Night* made the intricacy of observations of the moon more manageable for novice learners. Second, *Starry Night*'s interface allowed the participants to make more accurate measurements of angular separations between the sun, moon, and horizon than was possible with direct observations. Lastly, the students were able to make more observations with the computer, which allowed for better understandings of the shapes, patterns, and cause of moon phases.

Bell and Trundle (2008) studied preservice elementary school teachers' conceptual understanding about standards-based lunar concepts before and after inquiry-based instruction using *Starry Night Backyard*. The 50 participants were graduate students enrolled in a Masters of Education initial licensure program for early childhood education. The intervention integrated *Starry Night Backyard* with instruction of moon phases from *Physics by Inquiry* by Lillian McDermott (1996). The general inquiry-based approach and specific instructional activities were identical to those in previous investigations by Trundle et al. (2002, 2004, 2006, 2007a, 2007b). What made this study unique was that they chose to use *Starry Night Backyard* for moon observation instead of actual observations of the moon.

Prior to instruction, 96% of the preservice teachers included alternative, non-scientific phases in their moon drawings. Only 2 preservice teachers drew scientific moon phases. None of the participants were able to draw both scientific phases and scientific sequences. After instruction, 80% of participants drew scientific moon phases while 98% drew the correct moon phase sequences. In addition, the preservice teachers' ability to draw both scientific moon phases and sequences improved by 80%.

Trundle and Bell (2010) compared three groups of preservice teachers' employing guided inquiry-based instruction. The first group collected nine weeks of observational data using *Starry Night*. The second group collected three weeks of observational data from nature then collected the final six weeks of observational data using *Starry Night*. The third group collected nine weeks of observational data from nature. Before the treatments, 44% of the *Starry Night*-only group, 36.1% of the *Starry Night* + Nature group, and 56.5% of the Nature-only group held alternative conceptions with scientific fragments. 42% of the *Starry Night*-only group, 29.5% of the *Starry Night* + Nature group, and 28.3% of the Nature-only group held alternative conceptions. After the treatments, 84% of the *Starry Night*-only group, 68.9% of the *Starry Night* + Nature group, and 69.6% of the Nature-only group held scientific conceptions.

Statistically greater gains in all cases were demonstrated by the *Starry Night*-only treatment. No significant differences, however, were found among the three treatments in participants' abilities to draw scientific moon shapes or in their conceptions of the causes of moon phases. Therefore, Trundle and Bell (2010)

concluded that the three treatments were equally effective in facilitating the desired conceptual change.

### *Conceptual Change Research*

Conceptual change is the “the mechanism underlying meaningful learning. Conceptual change occurs when a learner moves from not understanding how something works to understanding it” (Mayer, 2002, p. 101). It requires a major reorganization of prior knowledge. According to Glynn and Duit (1995), a conception is the learner’s mental model of an object or event. Examples include the acquisition of the scientific concept of force that comes into conflict with the everyday concept of force as a property of objects (Chi, Slotta, & de Leeuw, 1994) and understanding the Copernican view of the solar system that comes into conflict with the geocentric view (Vosniadou & Brewer, 1994). In other words, conceptual change “denotes learning pathways from students’ pre-instructional conceptions to the science concepts to be learned” (Duit & Treagust, 2003, p. 673).

Windschitl and Andre (1998) listed four educational conditions that promote conceptual change. First, the student must experience dissatisfaction with an existing condition. Second, the new conception must be intelligible. Third, the new conception must be plausible. Lastly, the new conception must be fruitful.

In their study, Windschitl and Andre (1998) investigated the effects of exploratory and confirmatory learning environments on college students’ conceptual change. They also examined the potential interaction between student epistemological belief and the type of simulation environment. The exploratory group used “a computer-

based cardiovascular simulation exercise in a context-bound framework and was allowed to create and test hypotheses regarding cardiovascular phenomena” (Windschitl & Andre, 1998, p. 149). The confirmatory group completed “the same simulation exercise, but in a prescribed fashion to simply confirm information as directed by a written guide” (Windschitl & Andre, 1998, p. 149).

In the exploratory group, Windschitl and Andre (1998) found that students with more sophisticated epistemological beliefs performed better when allowed to explore while those with less sophisticated epistemological beliefs did poorly when asked to explore. However, the reverse was true in the confirmatory group. In addition, some evidence was found that exploratory computer simulation exercises, in some cases, can be significantly more effective than confirmatory exercises in changing students’ misconceptions.

Hobson, Trundle, and Sackes (2010) examined 21 children’s understanding of lunar concepts before and following an inquiry-based instruction utilizing *Starry Night* planetarium software. The children ranged in age from 7 to 9 years. Prior to the instruction, 76.2% of the children reported that the moon could only be observed at night while only one student reported that the moon could also be seen at times during the day. After the instruction, 95.2% of the children responded that the moon can sometimes be seen in the nighttime and 81% responded that the moon can also be seen during the daytime.

Prior to the instruction, 76.2% of the students reported that the phases of the moon appeared in a predicable sequence. After the instruction, all of the children



reported that the phases of the moon appeared in a predictable sequence. When asked to perform a card sorting task, only 19% of the students placed the cards into the scientific sequences prior to the instruction. After the instruction, 57.1% of the students placed the cards into the correct scientific pattern. Based on interviews, 52.4% of the students held alternative conceptual understandings about the cause of moon phases prior to the intervention. Only 33.3% of the students continued to hold an alternative understanding after the intervention.

### *Research on Inquiry-based Learning*

Most research defines four levels of inquiry: traditional hands-on, structured, guided, and open (Bell, Smentana, & Binns, 2005; Bonnstetter, 1998). Open inquiry is also called full inquiry or student-directed inquiry. Bonnstetter (1998) added a fifth level called student research.

Ohana (2006) also described some of the problems in teaching through inquiry. Teaching through inquiry requires more time and resources than teaching from the textbook or lecturing. This time requirement makes covering all the material in most textbooks, and in most state standards, impossible. This may make teaching through inquiry run counter to what some administrators require. Research, however, does support “the counterintuitive result that students who spend more time really learning a smaller, coherent amount of important content will perform as well or better on a comprehensive test than students who have been exposed to all of the content available to be put on the test” (Ohana, 2006, p. 65).

Minner, Levy, and Century (2010) synthesized findings from research between 1984 and 2002 in order to address the question, what is the impact of inquiry science instruction on K-12 student outcomes. They rated all the components of instruction for student active thinking, responsibility for learning and motivation. Those ratings were summed to reflect an overall level of inquiry saturation within each treatment with a maximum possible score of 44 points. Studies with sums ranging from 2 to 6 were categorized as low inquiry saturation. Studies with sums ranging from 8 to 16 were categorized as moderate inquiry saturation. Studies with sums ranging from 18 to 42 were categorized as high inquiry saturation.

Out of the 138 studies, 51% showed positive impacts of some level of inquiry science instruction on student content learning and retention. They found no statistical significant association between the amount of inquiry saturation and increased student science conceptual learning. They also found that teaching strategies that actively engage students in the learning process through scientific investigations were more likely to increase conceptual understanding than strategies that relied on more passive techniques.

Few studies have compared the types of inquiry-based learning with each other (Scallon, 2006; Yager, Abd-Hamid, & Akcay, 2005). Scallon (2006) compared the use of guided inquiry with authentic student research learning with eighth graders. She found that the guided inquiry students understood more about genetic concepts and environmental effects on phenotype than the authentic scientific research learning students. However, the authentic scientific research learning students understood more

about scientific investigation as a process than the guided inquiry students. In addition, the authentic scientific research learning students made greater gains in demonstrating practical reasoning skills.

Yager, Abd-Hamid, & Akcay (2005) compared how structured inquiry, guided inquiry, and full (open) inquiry affected 32 teachers' performance in terms of questioning strategies and other classroom actions. They came to eight conclusions based upon their results.

1. "Full inquiry works best when not preceded by structured and guided activities.
2. Beginning with structured, moving to guided second, and finally full inquiry results in the least effectiveness for a full inquiry experience.
3. Structured inquiry is not seen as inquiry with teachers participating in such an experience.
4. Guided inquiry causes most teachers in such an experiment to tend to focus on what they were guided to do when in a full inquiry situation.
5. There are basically far more curiosity questions when the full inquiry station occurs first.
6. Experiencing full inquiry first causes more discontent with structured inquiry.
7. There is less negativity with structured inquiry when it is experienced prior to guided and/or full inquiry.
8. Guided inquiry succeeds when teachers use higher order questions as the model for guiding" (Yager, Abd-Hamid, & Akcay, 2005, p. 433).

I have found no studies that compare the effects of structured inquiry, guided inquiry, and student-directed inquiry. I am looking to fill this gap. In addition, I will compare the results of the three treatment groups for three different grade levels: fifth, sixth, and seventh.

## CHAPTER III

### METHODOLOGY

#### *Introduction*

The first chapter of this dissertation described the potential of using inquiry-based learning and computer simulation software as an effective method for changing students' mental models. The second chapter reviewed the literature to support inquiry for changing students' mental models using inquiry-based learning and computer simulation software. This literature included research on seven specific areas of research: 1) mental models, 2) mental models in astronomy, 3) science misconceptions, 4) how classroom instruction changes mental models, 5) computer simulations, 6) conceptual change, and 7) inquiry-based learning.

#### *Conceptual Framework*

The conceptual framework underlying the design and implementation of this study was based upon the seven areas of literature reviewed in Chapter 2. Specifically, the framework used Bonnstetter's (1998) inquiry teaching continuum, Vosniadou and Brewer's (1992, 1994) experiments investigating elementary school students' conceptual knowledge about the Earth and the day/night cycle, and Bell & Trundle's (2006, 2008) and Trundle and Bell's (2005, 2010) investigation into conceptual understanding of moon phases using computer simulation software. Taken collectively, the review allowed me to demonstrate a need to extend mental models research into how students' mental models are formed and changed.

### *Purpose*

The purpose of this study was to compare middle school (i.e., fifth, sixth and seventh grade) students' mental models of the day/night cycle before and after implementation of three inquiry-based treatments. The three treatments were classified as 1) structured inquiry, 2) guided inquiry, and 3) student-directed inquiry. The treatments used activities from interactive simulation software to address the following questions:

1. What are the comparative effects of inquiry types on middle school students' mental models of the day/night cycle immediately following the inquiry intervention and three months later?
2. What mental models (e.g. initial, lower synthetic, upper synthetic, and scientific) do middle school students hold (a) prior to, (b) immediately after, and (c) three months after interventions using one of three inquiry types?
3. What interaction effect occurs between starting mental models and inquiry treatments?

### *Pilot Study*

The inspiration for my pilot study was reading Vosniadou and Brewer (1992, 1994), Diakidoy and Kendeou (2001), and Trundle and Bell (2006, 2008). These articles triggered a search for more information. Ultimately, this led to the design of my pilot study.

### *Purpose*

There were two main purposes of the pilot study. The first was to investigate how students' mental models were affected by the use of computer simulation software designed to teach about astronomy and the day/night cycle specifically. The second was to look for differences between the mental models of boys and girls. The participants were 5<sup>th</sup> & 6<sup>th</sup> graders in a private, parochial school in Houston, TX and 6<sup>th</sup> graders in a private, all-girls school in Baltimore, MD. A total of 111 students participated in the pilot study. Data were gathered using a 16-question pre-post instrument, adapted for the dissertation study, originally based on the work of Diakidoy and Kendeou (2001).

### *Results*

While not all the students' mental models were changed to scientific, there was significant movement in that direction ( $t=-6.414, p=0.00$ ). Four students scored 16 on the pretest, which indicated a scientific mental model. After the intervention, seventeen students scored 16 on the posttest. The overall mean of scores on the pretest was 12.63 while the overall mean of scores of the posttest was 13.9. A significant correlation between the pretest and the posttest was found ( $r = 0.424$  at the 0.01 level). In addition, the boys' overall mean scores on both the pretest and posttest were higher than the girls' overall mean scores. The results from this pilot study led me to modify it into the study that became my dissertation research.

### *Modifications*

As shown above, implementation during the pilot study occurred in three different classrooms. Students in all three classrooms used structured inquiry. In my

dissertation study, this was expanded to compare the effects of three different types of inquiry (structured, guided, and student-directed) on students' mental models.

The test used in my pilot study was also used in my dissertation study. In my pilot study, the test was used as a pretest and a posttest. However, in my dissertation study, the test was used as a pretest, an immediate posttest, and a delayed posttest. *Starry Night Middle School* (Imaginova Corp., 2005) was used in my pilot study and my dissertation study as the computer simulation software. I selected this program because it was easy to use and I could afford it. In addition, *Starry Night programs* had been used by other researchers including Bell and Trundle (2008) and Trundle and Bell (2010).

During these implementations, I developed three lessons. These lessons were tested, revised, and retested during my pilot study. Students in the Structured Inquiry group used the final version of these three lessons during my dissertation. Students in the Guided Inquiry group of my dissertation used lessons based on modifications generated during the pilot study. Students in the Student-directed Inquiry group of my dissertation used student-developed procedures. In the next section, I describe the methodology I used to investigate three research questions during my dissertation study.

## *Methods*

### *Mixed methods research*

A sequential mixed methods design (Onwuegbuzie & Leech, 2006) was used to address each of my three research questions (see Figure 3.1). First, a pretest was administered to all participating students. Second, from all participating students, several were chosen for interviews based on pretest scores. The three students with lowest

scores, three students with highest scores, and three students with average scores in each grade level were selected. Third, students were randomly assigned to treatment groups by classroom. Fourth, treatments were administered. Fifth, all participating students took the immediate posttest on the last day of the treatments. Sixth, immediate post-interviews were conducted with the previously selected students. Seventh, all participating students took the delayed posttest three months after the treatments. Eighth, the final set of interviews was conducted with the previously selected students three

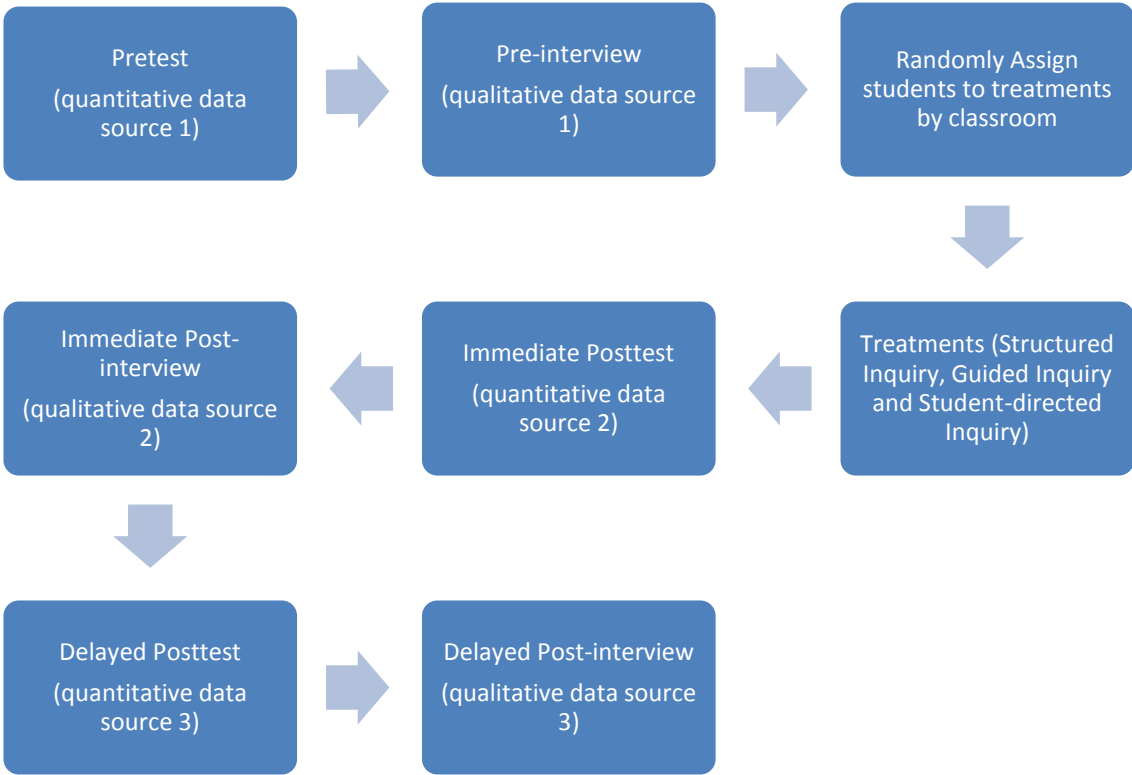


Figure 3.1. Sequential order of study & data collection.



months after the treatments. This series of multiple-choice tests (pre, immediate post, and delayed post) and interviews were the primary data sources.

*Participants*

The participants were 145 fifth, sixth, and seventh grade students who were purposively selected from a public school in a southcentral U.S. state. For the purpose of this study, the students remained in their classrooms. There were three classrooms per grade level. Those classrooms were randomly assigned to one of three treatments, structured, guided, and student-directed.

The participants in this study were situated in a rural district having 16.6% of students classified as Economically Disadvantaged and 1.3% of students classified as English as a Second Language. In addition, 17.9% of the students in the district were classified as At Risk.

Table 3.1  
*Student information by inquiry group and grade*

Inquiry Group	Students	Ethnicity		Grade	Number of students	Gender	
		White	Hispanic			Female	Male
Structured	47	44	3	5	17	8	9
				6	13	7	6
				7	17	9	8
Guided	51	46	5	5	16	6	10
				6	15	10	5
				7	20	13	7
Student-directed	47	44	3	5	15	7	8
				6	15	10	5
				7	17	9	8

The Structured Inquiry group was composed of 17 fifth graders, 13 sixth graders, and 17 seventh graders. The Guided Inquiry group was made up of 16 fifth graders, 15 sixth graders, and 20 seventh graders. The Student-directed Inquiry group was composed of 15 fifth graders, 15 sixth graders and 17 seventh graders (see Table 3.1).

### *Treatments*

As mentioned previously, treatments were based on the literature on classroom inquiry (Bell, Smentana, & Binns, 2005; Bonnstetter, 1998). The three treatments were implemented at three different grade levels. All three treatments used *Starry Night Middle School* interactive simulation software to investigate the phenomenon of the day/night cycle. Additionally, all three treatments were based on two researcher-developed lessons using *Starry Night* (See Appendix A).

### *Differences in Treatments*

Differences among the three treatments for the purpose of my research were 1) who decided what questions would be investigated, and 2) who designed the procedures (see Table 3.2). Students in both the Structured and Guided Inquiry groups investigated researcher-developed questions. In contrast, students in the Student-directed Inquiry group investigated their own questions developed with researcher approval.

Procedures were the second area where three treatments differed. The structured inquiry group used two researcher-developed lessons. The guided inquiry group used procedures developed by the students but approved by the researcher. The student-directed inquiry group used student-developed procedures with researcher input.

### *Structured Inquiry Group*

The structured inquiry group investigated researcher-developed questions about the day/night cycle using researcher-developed procedures. On the first day, three to four students worked together to explain 1) how the concept of a day changes over a year and 2) how the concept of a day changes by location. Students moved in four-minute cycles through a series of four tables where they considered the ideas of the previous students and added their own. When the students returned to their own table, they discussed all the ideas and led the class discussion for their question.

Over the next four days, the students used *Starry Night Middle School* software to collect their data using teacher-developed procedures. Collected data included times for sunrise and sunset at different times of the year, what objects were visible in the sky at a variety of times during the day, and where the sun was located in the sky at a variety of times during the day. The students evaluated earlier explanations using the collected data. On the final day, each student wrote a two to three paragraph conclusion to justify his or her explanation.

### *Guided Inquiry Group*

The guided inquiry group investigated researcher-developed questions about the day/night cycle using student-developed procedures. On the first day, three to four students worked together to explain 1) how the concept of a day changes over a year and 2) how the concept of a day changes by location. Students moved in four-minute cycles through a series of four tables where they considered the ideas of the previous students and added their own. When the students returned to their own table, they discussed all

the ideas and led the class discussion for their question. Students discussed how to investigate this phenomenon. The researcher approved the student-developed procedures to be used with *Starry Night Middle School* software.

Over the next four days, the students collected data using the procedures they developed. Collected data included times for sunrise and sunset at different times of the year, what objects were visible in the sky at a variety of times during the day, and where the sun was located in the sky at a variety of times during the day. The students evaluated earlier explanations using the collected data. On the final day, each student wrote a two to three paragraph conclusion to justify his or her explanation.

Table 3.2  
*Differences among treatment groups*

Research activity	Inquiry Group		
	Structured	Guided	Student-directed
Topic	Day/Night Cycle	Day/Night Cycle	Day/Night Cycle
Questions	Q1: How does a “day” change over a year? Q2: How does a “day” change by location?	Q1: How does a “day” change over a year? Q2: How does a “day” change by location?	<i>Students decided the questions with researcher input</i>
Procedures/Design	<i>Two researcher-developed lessons</i>	<i>Student-developed procedures with researcher input</i>	<i>Student-developed procedures with researcher input</i>
Results/Analysis	<i>Students interpret data and evaluate explanations with researcher input</i>	Students interpret data and evaluate explanations	Students interpret data and evaluate explanations
Conclusions	Students write up conclusions	Students write up conclusions	Students write up conclusions

### *Student-directed Inquiry Group*

The student-directed inquiry group investigated student-developed questions about the day/night cycle using student-developed procedures. On day one, students were separated into groups of three to four. Each group chose one question about the day/night cycle to investigate. Once each group's question was approved by the researcher, the students worked together to come up with an explanation for the phenomena. Students moved in four-minute cycles through a series of four tables where they considered the ideas of the previous students and added their own. Once the students returned to their table, they debated all the ideas and led the class discussion for their question.

After the researcher approved the student-developed questions and procedures, the students used *Starry Night Middle School* software to collect data over the next four days. Collected data included times for sunrise and sunset at different times of the year, what objects were visible in the sky at a variety of times during the day, and where the sun was located in the sky at a variety of times during the day. The students used the collected data to evaluate the explanations discussed in the earlier class period. On the final day, each student wrote a two to three paragraph conclusion to justify his or her explanation.

#### *Data Collection*

Both quantitative and qualitative data were collected to answer the three dissertation research questions. A 16-item, multiple-choice test was developed to collect quantitative data. A 23-item structured interview was developed to collect qualitative

data. In the section below, I present the instruments I used to collect data. The instruments are presented in the order that data was collected.

### *Instruments*

I worked with several graduate students and my co-chairs to develop a 16-question, multiple-choice test. That test was designed to measure prior knowledge, immediate post-treatment knowledge, and delayed retention three months later of the day/night cycle. The test was based upon Vosniadou and Brewer's (1992, 1994) questionnaire and Diakidoy and Kendeou's (2001) multiple-choice test. Running a Cronbach's  $\alpha$  gave a reliability of 0.523 for my test.

Each of the 16 questions was a content knowledge question about which students may have a misconception. For each question there was one answer choice that followed from the use of a scientific mental model and one or more answer choices that followed from the use of an initial or synthetic mental model. Answer choices that followed from the use of a scientific mental model were coded as a three. Answer choices that followed from the use of a synthetic mental model were coded as a two. Answer choices that followed from the use of an initial mental model were coded as a one. Coding choice for each answer was verified by my co-chairs.

Students' scores were coded as initial, lower synthetic, upper synthetic, and scientific. Students scoring 14 through 16 were coded as initial. Students scoring 17 through 29 were coded as lower synthetic while those scoring 30 through 40 were coded as upper synthetic. Students scoring 41 through 42 were coded as scientific.

Interview data were collected using a researcher-developed protocol. Working with other graduate students both before and after the pilot study allowed me to revise the 48-item questionnaire used by Vosniadou and Brewer (1992, 1994). I shortened it to a 23-item questionnaire covering the topics of the four researcher-developed lessons from the pilot study. This 23-item questionnaire was used during interviews to gather information about participants' knowledge of certain critical concepts in astronomy, including their ideas about the earth's shape and gravity (Appendix B).

#### *Pretest*

The 16-item multiple-choice test was administered to all students to measure their mental models of the day/night cycle before treatments. The teachers proctored the test and sent them to me for analysis.

#### *Pre-interviews*

Students from a purposive sample (n=14) were interviewed after the initial pretest to clarify student mental models of the day/night cycle. Students were selected based on their pretest scores. Table 3.3 presents the number of students interviewed by group. All interviews were audiotaped and transcribed.

Table 3.3  
*Number of students interviewed*

Inquiry group	Pre-interview	Immediate post-interview	Delayed post-interview
Structured	4	7	7
Guided	8	11	7
Student-directed	2	5	5

### *Immediate Posttest*

The last day of the treatments, the same 16-item, multiple-choice pretest was administered as the immediate posttest. This posttest was designed to measure students' mental models of the day/night cycle immediately following treatment. Questions were arranged differently from the pretest and can be found in Appendix C.

### *Immediate Post-interviews*

Twenty-three students were interviewed one week following the treatments and the immediate posttest. The number of students interviewed from each inquiry group is found in Table 3.3. Once again, interviews were audiotaped and transcribed. The interview questions can be found in Appendix B.

### *Delayed Posttest*

The pre/posttest was administered for a third time three months after the treatments as the delayed post-test. This posttest was designed to measure students' mental models of the day/night cycle three months following treatment. This posttest was compared to the other tests in order to examine the extent to which the desired movement toward scientific mental models was maintained over time. The teachers once again proctored the test and sent the m to me for analysis. Questions were arranged like the pretest and can be found in Appendix C.

### *Delayed Post-interviews*

Nineteen students were interviewed three months after the treatments. Four of the students who were previously interviewed were absent on the day of the delayed post-



interviews. The interviews were audiotaped and transcribed. The interview questions can be found in Appendix B.

### *Quantitative Data Analysis*

Three treatment groups took multiple-choice tests before, immediately after, and three months after implementation. These tests were scored according to the method described in chapter one. The tests were then analyzed using six quantitative methods: ANOVA, Pearson's correlations, nominal regression, exploratory factor analysis, Cronbach's  $\alpha$ , and Cohen's  $d$ .

#### *ANOVA*

An ANOVA with repeated measures was selected because testing was repeated three times during the treatments. An ANOVA with repeated measures was conducted to determine if the different treatments produced differences in student's mental models of scientific concepts held by participants before, immediately following, and three months after treatment. In the analysis the independent variable was inquiry type, the dependent variable was mental model type, and pretest was the covariate. There were three categories of inquiry type and three different mental model types.

#### *Pearson Correlations*

Pearson correlations were calculated using the standard deviations of the pretest, immediate posttest, and delayed posttest with covariances. The Pearson correlations were used to quantify the strength of linear dependence between the pretest and immediate posttest, the pretest and delayed posttest, and the immediate posttest and delayed posttest. The values for a Pearson's correlation fall between 0.00 and  $\pm 1.00$ . If

the variables are independent, Pearson's correlation coefficient is 0. The closer the coefficient is to either  $-1$  or  $1$ , the stronger the relationship between the variables.

#### *Cohen's d*

Cohen's  $d$  was selected to find effect size. Cohen's  $d$  was calculated using the standard deviations of the pretest, immediate posttest, and delayed posttest and their means. Cohen's  $d$  was used to measure of the strength of the relationships between the pretest and immediate posttest, the pretest and delayed posttest, and the immediate posttest and delayed posttest.

#### *Exploratory Factor Analysis*

An exploratory factor analysis was selected to identify the underlying relationships between measured variables. It was also used to identify a set of latent constructs underlying a battery of measured variables, in this case the test questions. There should be at least 3 to 5 measured variables per factor. The exploratory factor analysis was performed using the students' answers from the pretest.

#### *Nominal Regression*

Nominal regressions were used to predict the probabilities of the different possible outcomes of a categorically distributed dependent variable (answers to pretest questions), given a set of independent variables (inquiry groups).

#### *Cronbach's Alpha*

Cronbach's alpha was used to measure the reliability of the pretest. Cronbach's alpha will generally increase as the intercorrelations among test items increase. It is, therefore, known as an internal consistency estimate of reliability of test scores.

### *Qualitative Data Analysis*

Twenty-three students were selected from the three treatments. Due to absences 14 students were interviewed prior to the study. All twenty-three students were interviewed immediately after the study. Again due to absences, 19 students were interviewed three months after the study. Interviews were conducted using a 23-item questionnaire. The purpose was to determine the mental model type held by the students before, immediately after and three months after the treatments. Individual transcripts were created from the interview tapes. Those transcripts were my source of qualitative data.

### *Constant Comparative*

The constant comparative method (Glaser & Strauss, 1967) was used to analyze student interview transcripts. I first coded each of the transcripts. Second, I compared the codes and grouped them into concepts. Third, I categorized those concepts into mental model types. Last, I created tables to display the students' mental model before, immediately after, and three months after the treatments for each treatment group (see Table 3.4).

Table 3.4  
*Sample table of students' mental models*

Student	Inquiry Group	Grade	Pre-Interview	Pretest	Immediate Post-Interview	Immediate Posttest	Delayed Post-Interview	Delayed Posttest
Susan	Structured	5	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic
Amber	Structured	6	Synthetic	Synthetic	Synthetic	Scientific	Synthetic	Synthetic
Caitlin	Structured	7	Scientific	Scientific	Scientific	Scientific	Scientific	Scientific
Thomas	Guided	5	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic
Joseph	Guided	6	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic
Seth	Guided	7	Scientific	Synthetic	Synthetic	Scientific	Synthetic	Synthetic
Shenifa	Student-directed	5	Initial	Initial	Synthetic	Synthetic	Synthetic	Synthetic
Brigitta	Student-directed	6	Initial	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic
Lynda	Student-directed	7	Scientific	Synthetic	Synthetic	Scientific	Synthetic	Synthetic

## CHAPTER IV

### RESULTS

#### *Introduction*

The first chapter of this dissertation described the potential of using inquiry-based learning and computer simulation software as an effective method for changing students' mental models. The second chapter reviewed the literature that supports changing students' mental models using inquiry-based learning and computer simulation software. This literature included research on seven specific areas of research: 1) mental models, 2) mental models in astronomy, 3) science misconceptions, 4) how classroom instruction changes mental models, 5) computer simulations, 6) conceptual change, and 7) inquiry-based learning. The third chapter of this dissertation described the methodology used in my research study.

#### *Results*

##### *Research Question 1*

The first research question asked: What are the comparative effects of inquiry types on middle school students' mental models of the day/night cycle immediately following and three months following?

##### Quantitative Data Analysis

Each of the three inquiry groups was composed of one fifth grade, one sixth grade, and one seventh grade class. The three groups had similar means on the pretest, as shown in Table 4.1. There was no significant difference among the groups ( $F=0.70$ ,

$p=0.50$ ). As expected, pretest score, immediate posttest score, and delayed posttest score were found to have a strong positive correlation with each other (see Table 4.2). The correlation between the pretest and the immediate posttest was significant ( $r=0.434$ ). The correlation between the pretest and the delayed posttest was significant ( $r=0.415$ ). The correlation between the immediate pretest and the delayed posttest was significant ( $r=0.614$ ). These three variables represented repeated measures of the same factor.

Table 4.1  
*Means and standard deviations for Structured, Guided, and Student-directed inquiry groups*

	Structured Inquiry Group	Guided Inquiry Group	Student-directed Inquiry Group
Pretest	34.05(4.25)	33.98(3.99)	35.24(3.01)
Immediate Posttest	37.64(2.98)	37.89(2.76)	36.89(2.86)
Delayed Posttest	36.84(3.43)	37.17(2.27)	37.00(3.03)

Table 4.2  
*Correlations of scores for all groups ( $\alpha=0.05$ )*

	Pretest	Immediate Posttest	Delayed Posttest
Pretest	1	0.434	0.415
Immediate Posttest		1	0.614
Delayed Posttest			1

Results from a repeated measures ANOVA showed (see Table 4.3) that the three inquiry group treatments did not appear to have a significantly different effect on students' mental models of the day/night cycle ( $F=2.00$ ,  $p=0.139$ ). However as shown in Table 4.4, time (prior to the intervention, immediately after, and three months after) did

appear to have a significant negative effect on students' mental models of the day/night cycle ( $F=4.84, p=0.030$ ). Additionally, the interaction between inquiry group and time also did not have a significant effect on students' mental models of the day/night cycle ( $F=1.66, p=0.193$ ), as the results from a repeated measures ANOVA showed (see Table 4.4).

Table 4.3  
*Repeated measures ANOVA between subjects effects*

Source	Df	SS	MS	F	P
Pretest	1	422.09	422.09	40.59	0.00
Inquiry Group	2	41.68	20.84	2.00	0.139
Inquiry Group x Pretest	2	17.26	8.63	0.83	0.438
Error	134	1393.42	10.40		

Table 4.4  
*Repeated measures ANOVA within subjects effects*

Source	Df	SS	MS	F	P
Time	1	15.56	15.56	4.84	0.030
Time x Pretest	1	0.34	0.34	0.11	0.747
Inquiry Group x Time	2	10.70	5.35	1.66	0.193
Time x Inquiry Group x Pretest	2	2.55	1.27	0.40	0.674
Error	134	464.25	3.22		

The effect size for the difference between the Structured Inquiry group and the Guided Inquiry group immediately following the intervention was small. The percentage of nonoverlap between the two groups was 7.7%. Three months following the intervention, both the effect size and the percentage of nonoverlap between the two groups remained the same (see Table 4.5).

The effect size for the difference between the Structured Inquiry group and the Student-directed Inquiry group immediately following the intervention was small. The percentage of nonoverlap between these two groups was 14.7%. Three months following the intervention, the effect size remained small while the percentage of nonoverlap between the two groups dropped to 7.7% (see Table 4.5).

Table 4.5  
*Effect size*

	Structured & Guided Inquiry groups		Structured & Student-directed Inquiry groups		Guided & Student-directed Inquiry groups	
	Immediate Post	Delayed Post	Immediate Post	Delayed Post	Immediate Post	Delayed Post
Cohen's d	0.09	0.13	0.34	0.08	0.24	0.05
Pearson's correlation	0.05	0.06	0.17	0.04	0.12	0.02

The effect size for the difference between the Guided Inquiry group and the Student-directed Inquiry group immediately following the intervention was medium. The percentage of nonoverlap between the two groups was 21.3%. Three months following the intervention, the effect size was small and the percentage of nonoverlap between the two groups was 7.7% (see Table 4.5).

Comparisons of the pretest, immediate posttest and delayed posttest scores for the Structured Inquiry group revealed that they were strongly positively correlated with each other (see Table 4.6). The correlations, interestingly, were stronger for the



Structured Inquiry group than the correlations for the three inquiry groups combined as well as for the Guided Inquiry group and the Student-directed inquiry group.

Table 4.6

*Correlations of test scores for Structured Inquiry group ( $\alpha=0.05$ )*

	Pretest	Immediate Posttest	Delayed Posttest
Pretest	1	0.499	0.471
Immediate Posttest		1	0.704
Delayed Posttest			1

As shown in Table 4.7, the correlations of the pretest, immediate posttest and delayed posttest for the Guided Inquiry group were strong and positive. As shown in Table 4.8, the correlations among the pretest, immediate posttest and delayed posttest were strong and positive for the Student-directed Inquiry group.

Table 4.7

*Correlations of test scores for Guided Inquiry group ( $\alpha=0.05$ )*

	Pretest	Immediate Posttest	Delayed posttest
Pretest	1	0.426	0.391
Immediate Posttest		1	0.639
Delayed Posttest			1

Table 4.8

*Correlations of test scores for Student-directed Inquiry group ( $\alpha=0.05$ )*

	Pretest	Immediate Posttest	Delayed Posttest
Pretest	1	0.478	0.401
Immediate Posttest		1	0.521
Delayed Posttest			1

When I ran the exploratory factor analysis, the questions loaded on three factors. Due to estimated residual variances, questions four, seven, twelve, and fourteen were removed and the exploratory factor analysis rerun with the remaining twelve questions. Table 4.9 shows the factor loadings for each of those twelve questions.

Table 4.9  
*Factor loadings for the pretest*

Question numbers	Pretest questions	Factor 1	Factor 2	Factor 3
1	What do you think the Earth looks like?	0.010	0.095	-0.298
2	Which of the following drawings do you think shows best the shape of the Earth?	0.574	-0.143	0.005
3	If we travel directly eastward, we will eventually (a) meet the edge of the Earth, (b) fall off the edge of the Earth, or (c) pass the point where we started	0.195	0.615	0.083
5	Is there something that holds the Earth in one place?	-0.202	0.680	-0.019
6	Which of the following statements do you think is correct? (a) the Earth orbits the sun, (b) the sun orbits the Earth, or (c) neither the Earth nor the sun move	-0.012	0.466	0.039
8	During the day, the sun: (a) shines all over the Earth or (b) shines on our side of the Earth only	1.000	0.002	-0.454
9	In the sky, during the day, there is: (a) only the sun or (b) the sun and the stars	-0.164	0.060	0.611
10	During the night, the sun (a) goes behind a cloud, (b) moves to the other side of the Earth, or (c) shines on the other side of the Earth	0.001	0.326	0.279
11	When it is day in the United States, it is also day in all the other countries on the Earth.	0.073	0.371	0.320
13	Does the length of day and night change?	0.330	0.005	0.339
15	Does the sun set at the same time everyday?	-0.309	-0.007	0.506
16	Do the stars appear to move?	0.003	-0.628	0.778

Questions two and eight loaded on factor one. Question two, which addressed the shape of the Earth, had a value of 0.574. Question eight, which addressed which parts of the Earth receive sunlight during the day, had a value of 1. The shape of the Earth would be the topic that links both questions. Table 4.10 showed the variance for factor one. Figure 4.1 showed the eigenvalue for factor one.

Table 4.10  
*Variance per factor*

Factor	Variance
1	21.82%
2	14.99%
3	13.92%
4	10.53%
5	9.18%
6	7.63%
7	6.19%
8	4.61%
9	4.54%
10	3.09%
11	2.11%
12	1.39%

Questions three, five, six, ten, and eleven loaded on factor two. Question three, addressed whether or not the Earth has an edge. Question five addressed whether the Earth is held in one place. Question ten addressed what happens to the Sun at night. Question eleven addressed whether or not it is daytime all over the Earth at the same time. The majority of the questions dealt with the motion of the Sun and Earth. Table 4.10 showed the variance for factor two. Figure 4.1 showed the eigenvalue for factor two.

Questions nine, thirteen, fifteen, and sixteen loaded on factor three. Question nine addressed what objects are in the daytime sky. Question thirteen addressed whether or not the length of day and night changes. Question fifteen addressed whether or not the time of sunset changes. Question sixteen addressed whether or not the stars appear to move. The majority of the questions dealt with things that change in the day/night cycle. Table 4.10 showed the variance for factor three. Figure 4.1 showed the eigenvalue for factor three.

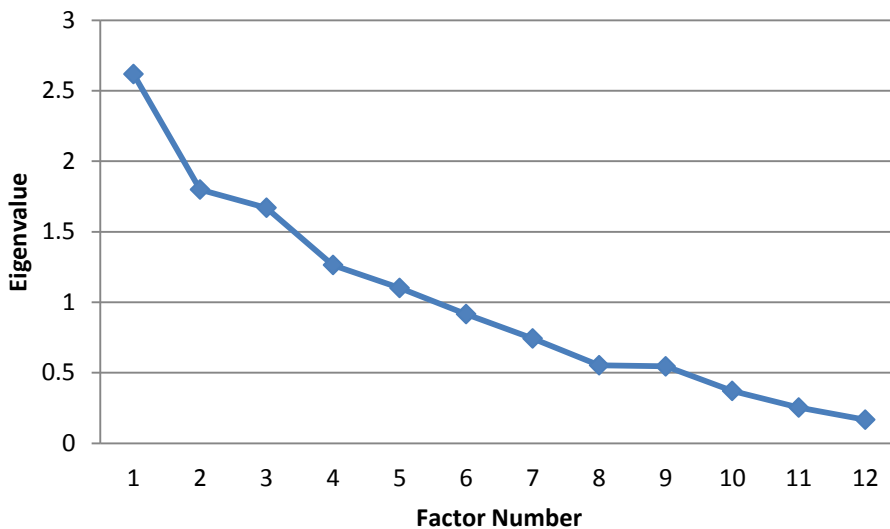


Figure 4.1. Scree plot of eigenvalues for each factor

In the Structured Inquiry group, ten of the sixteen test questions had an increase in the percentage of students who answered them correctly from pretest to immediate posttest. The greatest increase was 45.45% for question sixteen while the smallest

increase was 2.27% for question four. As shown in Table 4.11, the correlations for the percentages of students who answered test questions correctly amongst the pretest, immediate posttest and delayed posttest for the Structured Inquiry group were strongly positive. The correlation between the percentage of students who answered test questions correctly on the pretest and the immediate posttest was significant ( $r = 0.772$ ,  $p < 0.01$ ). The correlation between the percentage of students who answered test questions correctly on the pretest and the delayed posttest was significant ( $r = 0.845$ ,  $p < 0.01$ ). The correlation between the percentage of students who answered test questions correctly on the immediate posttest and the delayed posttest was significant ( $r = 0.887$ ,  $p < 0.01$ ).

Table 4.11  
*Correlations of percentages correct for Structured Inquiry Group ( $\alpha = 0.05$ )*

Variables	Pretest	Immediate Posttest	Delayed Posttest
Pretest	1	0.804	0.842
Immediate Posttest		1	0.904
Delayed Posttest			1

In the Guided Inquiry Group, eleven out of sixteen questions had increase in the percentage of students who answered them correctly from pretest to immediate posttest. The question with the greatest increase was thirteen, which saw an increase of 40.00% from pretest to immediate posttest. The question with the smallest increase was question eleven, which had a change of 2.00%. As shown in Table 4.12, the correlations for this amongst the pretest, immediate posttest and delayed posttest for the Guided Inquiry

group were strongly positive. The correlation between the percentage of students who answered test questions correctly on the pretest and the immediate posttest was significant ( $r=0.804$ ,  $p=0.01$ ). The correlation between the percentage of students who answered test questions correctly on the pretest and the delayed posttest was significant ( $r=0.842$ ,  $p=0.01$ ). The correlation between the percentage of students who answered test questions correctly on the immediate posttest and the delayed posttest was significant ( $r=0.904$ ,  $p=0.01$ ).

Table 4.12  
*Correlations of percentages correct for Guided Inquiry Group ( $\alpha=0.05$ )*

Variables	Pretest	Immediate Posttest	Delayed Posttest
Pretest	1	0.804	0.842
Immediate Posttest		1	0.904
Delayed Posttest			1

In the Student-directed Inquiry Group, twelve out of sixteen questions had an increase in the percentage of students who answered them correctly from pretest to immediate posttest. The question with the greatest increase was sixteen, which saw an increase of 32.61% from pretest to immediate posttest. The questions with the smallest increase were three and twelve, which both had a change of 2.18%. As shown in Table 4.13, the correlations for this amongst the pretest, immediate posttest and delayed posttest for the Student-directed Inquiry group were strongly positive. The correlation between the percentage of students who answered test questions correctly on the pretest

and the immediate posttest was significant ( $r=0.895$ ,  $p=0.01$ ). The correlation between the percentage of students who answered test questions correctly on the pretest and the delayed posttest was significant ( $r=0.898$ ,  $p=0.01$ ). The correlation between the percentage of students who answered test questions correctly on the immediate posttest and the delayed posttest was significant ( $r=0.929$ ,  $p=0.01$ ).

Table 4.13  
Correlations of percentages correct for Student-directed Inquiry Group ( $\alpha=0.05$ )

Variables	Pretest	Immediate Posttest	Delayed Posttest
Pretest	1	0.895	0.898
Immediate Posttest		1	0.929
Delayed Posttest			1

Of the sixteen questions on the pretest, there were four questions answered correctly by less than fifty percent of the students in all three inquiry groups: questions 5, 9, 13 and 16. These questions covered content over which the students had misconceptions. The results from the immediate and delayed posttest also provided an excellent comparison of the differences in the effect of the three inquiry groups on students' mental models of the day/night cycle.

First, question five was answered correctly by less than 50% of the students. It was "Is there something that holds the Earth in one place? In the Structured Inquiry group, 36.36% of the students answered this question correctly on the pretest. Of the students who answered incorrectly, 63.64% chose the answer choice that followed from

the use of an initial mental model. 32.00% of the students in the Guided Inquiry group answered this question correctly on the pretest. Of the students who answered incorrectly, 68.00% chose the answer choice that followed from the use of an initial mental model. In the Student-directed Inquiry group, 43.48% of the students answered this question correctly on the pretest (see Figure 4.2). Of the students who answered incorrectly, 56.52% chose the answer choice that followed from the use of an initial mental model.

Second, less than 50% of the students answered question nine correctly. It was “In the sky, during the day, there is (a) only the sun (b) the sun and the stars.” In the Structured Inquiry group, 25.00% of the students answered this question correctly on the pretest. Of the students who answered incorrectly, 75.00% chose the answer choice that followed from the use of an initial mental model. 24.00% of the students in the Guided Inquiry group answered this question correctly on the pretest. Of the students who answered incorrectly, 76.00% chose the answer choice that followed from the use of an initial mental model. In the Student-directed Inquiry group, 30.43% of the students answered this question correctly on the pretest (see Figure 4.2). Of the students who answered incorrectly, 69.57% chose the answer choice that followed from the use of an initial mental model.

Third, less than 50% of the students answered question thirteen correctly. It was “Does the length of day and night change?” Of the students in the Structured Inquiry group, 34.09% answered question thirteen correctly on the pretest. Of the students who answered incorrectly, 45.45% chose the answer that followed from the use of a synthetic



mental model and 18.18% chose the answer that followed from the use of an initial mental model. 34.00% of the students in the Guided Inquiry group answered this question correctly on the pretest. Of the students who answered incorrectly, 52.00% chose the answer that followed from the use of a synthetic mental model and 14.00% chose the answer that followed from the use of an initial mental model. In the Student-directed Inquiry group, 32.61% of the students answered question thirteen correctly (see Figure 4.2). Of the students who answered incorrectly, 54.35% chose the answer that followed from the use of a synthetic mental model and 13.04% chose the answer that followed from the use of an initial mental model.

Fourth, fewer than 50% of the students answered question sixteen correctly on the pretest. It was “Do the stars appear to move?” On the pretest, 38.64% of the students in the Structured Inquiry group answered this question correctly. Of the students who answered incorrectly, 56.82% chose the answer that followed from the use of an initial mental model. In the Guided Inquiry group, 42.00% of the students answered question sixteen correctly on the pretest. Of the students who answered incorrectly, 58.00% chose the answer that followed from the use of an initial mental model. 36.96% of the students in the Student-directed Inquiry group answered the question correctly on the pretest (see Figure 4.2). Of the students who answered incorrectly, 63.04% chose the answer that followed from the use of an initial mental model.

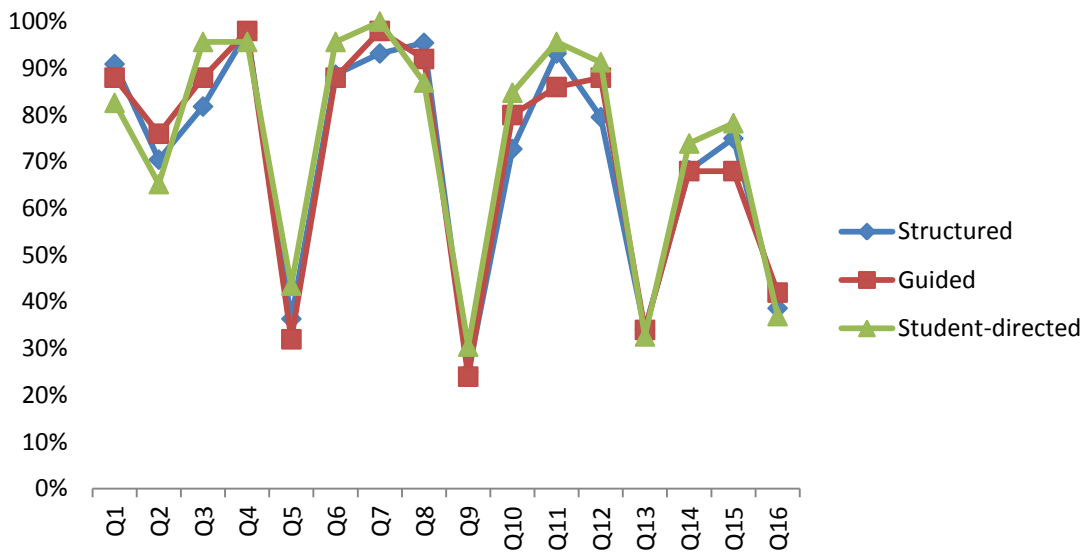


Figure 4.2. Percentage of students answering correctly on the pretest.

On the immediate posttest, question five was answered correctly by 45.45% of the students in the Structured Inquiry group, which was an increase of 9.09%. Of the students who answered incorrectly, 52.27% chose the answer that followed from the use of an initial mental model. The Guided Inquiry group had 48.00% of the students answer the question correctly. This was an increase of 16.00%. Of the students who answered incorrectly, 52.00% chose the answer that followed from the use of an initial mental model. The Student-directed Inquiry group had 36.96% of the students answer question five correctly (see Figure 4.3). This was a decrease of 6.52% (Table 4.14). Of the students who answered incorrectly, 60.87% chose the answer that followed from the use of an initial mental model.

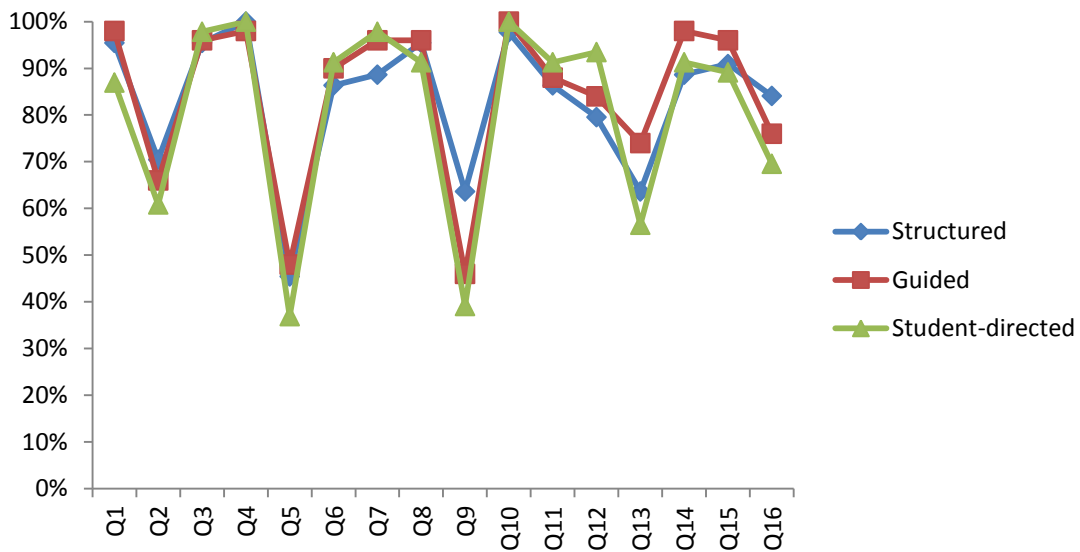


Figure 4.3. Percentage of students answering correctly on the immediate posttest.

Table 4.14

*Change in the percentage of students who answered correctly from pretest to immediate posttest*

	Structured Inquiry Group	Guided Inquiry Group	Student-directed Inquiry Group
Q1	4.54%	10.00%	4.35%
Q2	0.00%	-10.00%	-4.35%
Q3	13.63%	8.00%	2.18%
Q4	2.27%	0.00%	4.35%
Q5	9.09%	16.00%	-6.52%
Q6	-2.28%	2.00%	-4.35%
Q7	-4.54%	-2.00%	-2.17%
Q8	0.00%	4.00%	4.34%
Q9	38.64%	22.00%	8.70%
Q10	25.00%	20.00%	15.22%
Q11	-6.82%	2.00%	-4.35%
Q12	0.00%	-4.00%	2.18%
Q13	29.55%	40.00%	23.91%
Q14	20.46%	30.00%	17.39%
Q15	15.91%	28.00%	10.87%
Q16	45.45%	34.00%	32.61%

On the immediate posttest, 63.64% of the students in the Structured Inquiry group answered question nine correctly. This was a substantial increase of 38.64% from the pretest. Of the students who answered incorrectly, 36.36% chose the answer that followed from the use of an initial mental model.

In the Guided Inquiry group, 46% of the students answered question nine correctly on the immediate posttest. This was an increase of 22.00% from those who answered correctly on the pretest but not as large an increase as seen in the Structured Inquiry group. Of the students who answered incorrectly, 54.00% chose the answer that followed from the use of an initial mental model.

As shown in Figure 2.3, the Student-directed group had 39.23% of the students answer question nine correctly on the immediate posttest. This was an increase of 8.70% from the percentage of students who answered correctly on the pretest as shown in Table 4.13. Of the students who answered incorrectly, 60.87% chose the answer that followed from the use of an initial mental model.

On the immediate posttest, 63.64% of the students in the Structured Inquiry group answered question thirteen correctly. This was an increase of 29.55% from the number of students who answered correctly on the pretest. Of the students who answered incorrectly, 27.27% chose the answer that followed from the use of a synthetic mental model and 9.09% chose the answer that followed from the use of an initial mental model.

In the Guided Inquiry group, 74.00% of the students answered question thirteen correctly on the immediate posttest. This was a significant increase of 40.00% from the

pretest. Of the students who answered incorrectly, 22.00% chose the answer that followed from the use of a synthetic mental model and 4.00% chose the answer that followed from the use of an initial mental model.

As shown on Figure 4.3, the Student-directed Inquiry group had 56.52% of the students answer question thirteen correctly on the immediate posttest. This was an increase of 23.91% from the pretest as seen in Table 4.14. Of the students who answered incorrectly, 41.30% chose the answer that followed from the use of a synthetic mental model and 2.17% chose the answer that followed from the use of an initial mental model.

In the Structured Inquiry group, 84.09% of the students correctly answered question sixteen on the immediate posttest. This represented a significant increase of 45.45% from the pretest. Of the students who answered incorrectly, 15.91% chose the answer that followed from the use of an initial mental model.

On the immediate posttest, 76.00% of the students in the Guided Inquiry group answered question sixteen correctly. This was an increase of 34.00% from the pretest. Of the students who answered incorrectly, 24.00% chose the answer that followed from the use of an initial mental model.

As shown on Figure 4.3, 69.57% of the students in the Student-directed Inquiry group answered question sixteen correctly on the immediate posttest. This was an increase of 32.16% from the pretest (see Table 4.14). Of the students who answered incorrectly, 30.43% chose the answer that followed from the use of an initial mental model.

Table 4.15

*Change in the percentage of students who answered correctly from pretest to delayed posttest*

	Structured Inquiry Group	Guided Inquiry Group	Student-directed Inquiry Group
Q1	4.54%	2.00%	6.52%
Q2	-13.63%	-6.00%	10.87%
Q3	13.63%	8.00%	4.35%
Q4	2.27%	2.00%	4.35%
Q5	2.28%	-4.00%	-13.05%
Q6	2.27%	0.00%	-2.17%
Q7	2.27%	-4.00%	0.00%
Q8	2.28%	4.00%	6.52%
Q9	40.91%	32.00%	21.74%
Q10	6.82%	4.00%	-4.35%
Q11	-6.82%	12.00%	-2.17%
Q12	4.54%	-2.00%	0.00%
Q13	2.27%	30.00%	17.39%
Q14	20.46%	28.00%	10.87%
Q15	11.36%	28.00%	10.87%
Q16	27.27%	20.00%	32.61%

On the delayed posttest, the percentage of students in the Structured Inquiry group who answered question five correctly was 38.64%. The change in percentage from the pretest was 2.28%. Of the students who answered incorrectly, 61.36% chose the answer that followed from the use of an initial mental model. In the Guided Inquiry group 28.00% of the students answered question five correctly on the delayed posttest. This was a decrease of 4% from the pretest. Of the students who answered incorrectly, 74.00% chose the answer that followed from the use of an initial mental model. The Student-directed Inquiry group, as shown in Figure 4.4, had 30.43% of the students answer question five correctly on the delayed posttest. As Table 4.15 showed, this was a decrease of 13.05% from the pretest. Of the students who answered incorrectly, 69.57% chose the answer that followed from the use of an initial mental model

On the delayed posttest, the Structured Inquiry group had 65.91% of the students who answered question nine correctly. This was a change of 40.91% from the pretest. Of the students who answered incorrectly, 34.09% chose the answer that followed from the use of an initial mental model. The Guided Inquiry group's percentage of students answering question nine correctly increased to 56.00% on the delayed posttest. This was a change of 32.00% from the pretest. Of the students who answered incorrectly, 44.00% chose the answer that followed from the use of an initial mental model. The Student-directed Inquiry group, as seen in Figure 4.4, had 52.17% of the students answer question nine correctly on the delayed posttest. This was a change of 21.74% from the pretest (see Table 4.15). Of the students who answered incorrectly, 47.83% chose the answer that followed from the use of an initial mental model.

On the delayed posttest, 36.36% of the students in the Structured Inquiry group answered question thirteen correctly. The change in percentage answered correctly for question thirteen from pretest to delayed posttest for this group was 2.27%. Of the students who answered incorrectly, 63.64% chose the answer that followed from the use of a synthetic mental model. The percentage of students who answered question thirteen correctly in the Guided Inquiry group was 62.00%. This was a change of 30.00% from the pretest to the delayed posttest. Of the students who answered incorrectly, 34.00% chose the answer that followed from the use of a synthetic mental model and 4.00% chose the answer that followed from the use of an initial mental model. In the Student-directed Inquiry group, half the students answered question thirteen correctly on the delayed posttest as shown in Figure 4.4. As Table 4.15 shows, from the pretest this was a

change of 17.39%. Of the students who answered incorrectly, 45.65% chose the answer that followed from the use of a synthetic mental model and 4.35% chose the answer that followed from the use of an initial mental model.

The Structured Inquiry group had a percentage of students who correctly answered question sixteen on the delayed posttest that was 65.91%. The change in the percentage was 27.27% from the pretest. Of the students who answered incorrectly, 31.82% chose the answer that followed from the use of an initial mental model. On the delayed posttest, 62.00% of the students in the Guided Inquiry group answered question sixteen correctly. This was an increase 20.00% from the pretest. Of the students who answered incorrectly, 38.00% chose the answer that followed from the use of an initial mental model. The Student-directed Inquiry group had 69.57% of students answer question sixteen correctly (see Figure 4.4). This was an increase of 32.61% from the pretest (see Table 4.15). Of the students who answered incorrectly, 30.43% chose the answer that followed from the use of an initial mental model.



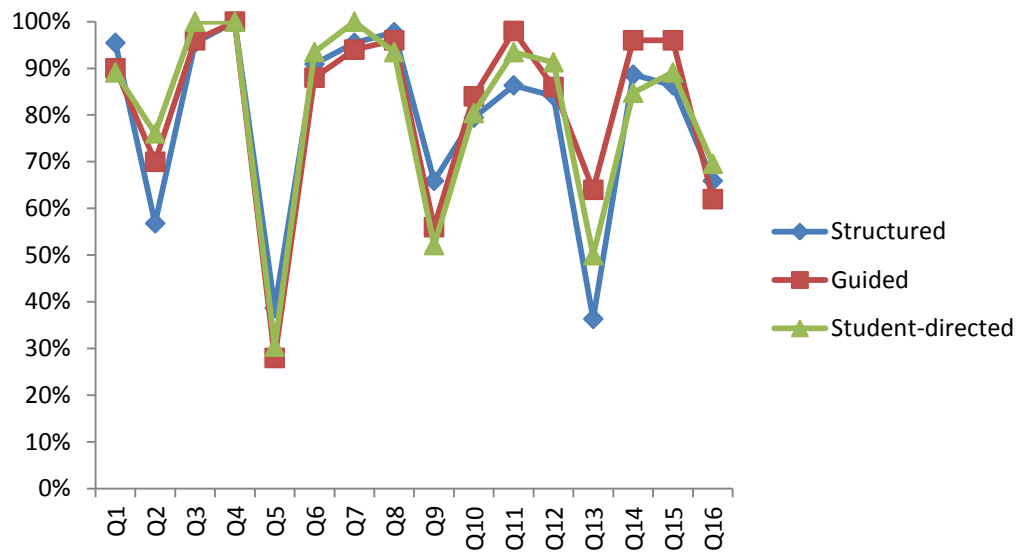


Figure 4.4. Percentage of students answering correctly on the delayed posttest.

In summary, the comparative effects of Structured Inquiry, Guided Inquiry, and Student-directed Inquiry on middle school students' mental models of the day/night cycle immediately following the intervention revealed no statistical difference among the three treatments. Time, however, appeared to have a significant negative effect on students' mental models of the day/night cycle. A comparison of the three groups' change in percentages correct from pretest to immediate posttest showed the Guided Inquiry group had the highest percentage change for eight of the questions, the Structured Inquiry group had the highest percentage change for five of the questions, and the Student-directed Inquiry group had the highest percentage change for three of the questions.

A comparison of the three groups' change in percentages correct from pretest to delayed posttest showed the Guided Inquiry group had the highest percentage change for

four of the questions, the Structured Inquiry group had the highest percentage change for seven of the questions, and the Student-directed Inquiry group had the highest percentage change for five of the questions.

### *Research Question 2*

The second research question was: What mental models (e.g. initial, lower synthetic, upper synthetic and scientific) do middle school students hold (a) prior to, (b) immediately after, and (c) three months after interventions using one of three inquiry types?

### Quantitative Data Analysis

Students scoring 14 through 16 were coded as initial. Students scoring 17 through 29 were coded as lower synthetic while those scoring 30 through 40 were coded as upper synthetic. Students scoring 41 through 42 were coded as scientific.

Prior to the interventions, no students held an initial mental model of the day/night cycle. Eleven students held a lower synthetic mental model of the day/night cycle. Their average score was 26.64 and they represented 7.86% of the students. One hundred and twenty-four students held an upper synthetic mental model of the day night cycle. Their average score was 33.08 and they represented 88.57% of the students. Five students held a scientific mental model of the day/night cycle. Their average score was 41.8 and they represented 3.57% of the students.

Immediately after the interventions, none of the students held an initial mental model of the day/night cycle. One student held a lower synthetic mental model of the day/night cycle. Her score was 28 and she represented 7.86% of the students. One

hundred and twenty-four students held an upper synthetic mental model of the day/night cycle. Their average was 37.05 and they represented 88.57% of the students. Fifteen students held a scientific mental model of the day/night cycle. Their average was 41.73 and they represented 10.71% of the students.

Three months after the interventions, none of the students held an initial mental model of the day/night cycle. Two students held a lower synthetic mental model of the day/night cycle. Their average was 28.5 and they represented 1.43% of the students. One hundred and twenty-three students held an upper synthetic mental model of the day/night cycle. Their average was 36.64 and they represented 87.86% of the students. Fifteen students held a scientific mental model of the day/night cycle. Their average was 41.33 and they represented 10.71% of the students.

As shown in Table 4.15, the Structured Inquiry group had a total of 44 students: 17 fifth graders, 13 sixth graders, and 14 seventh graders. None of the students held an initial mental model of the day/night cycle prior to the intervention. Four students were found to hold a lower synthetic mental model of the day/night cycle. Their average was 25.5 and they represented 9.09% of the Structured Inquiry group. Thirty-nine students held an upper synthetic mental model of the day/night cycle. Their average was 34.72 and they represented 88.64% of the Structured Inquiry group. One student was found to hold a scientific mental model of the day/night cycle. Her score was 42 and she represented 2.27% of the Structured Inquiry group.

\*\*\*\*\*On the immediate posttest, the Structured Inquiry group still had no students holding an initial mental model of the day/night cycle. The number of students holding a lower

synthetic mental model of the day/night cycle decreased to zero in the Structured Inquiry group on the immediate posttest. There were still thirty-nine students who held an upper synthetic mental model of the day/night cycle. Their average was 37.13 and they represented 88.64% of the Structured Inquiry group. Five students held a scientific mental model of the day/night cycle (see Table 4.17). Their average was 41.6 and they represented 11.36% of the Structured Inquiry group.

As shown in Table 4.16, the Structured Inquiry group's mean on the immediate posttest increased from the mean on the pretest. The standard deviation also changed. Interestingly, the minimum score on the immediate posttest increased from twenty-one to thirty, which fell within the upper synthetic range. The maximum score did not change.

Lastly, on the delayed posttest, in the Structured Inquiry group, no students held an initial mental model of the day/night cycle. There was an increase to two in the number of students holding a lower synthetic mental model of the day/night cycle on the delayed posttest (see Table 4.19). Their average was 28.5 and they represented 4.54% of the Structured Inquiry group. The number of students holding an upper synthetic mental model of the day/night cycle decreased to thirty-five. Their average was 36.43 and they represented 79.55% of the Structured Inquiry group. Seven students held a scientific mental model of the day/night cycle. Their average was 41.29 and they represented 15.91% of the Structured Inquiry group.

Table 4.16

*The means, minimums, maximums & standard deviations of scores*

	Structured Inquiry Group (N=44)				Guided Inquiry Group (N=50)				Student-directed Inquiry Group (N=46)				All Groups (N=140)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Pretest Score	34.05	4.25	21	42	33.98	3.99	25	42	35.24	3.01	30	42	34.51	3.79	21	42
Immediate Posttest Score	37.64	2.98	30	42	37.89	2.76	30	42	36.89	2.86	28	42	37.49	2.88	28	42
Delayed Posttest Score	36.84	3.43	28	42	37.17	2.27	33	42	37.00	3.03	30	42	37.03	2.89	28	42

Table 4.17

*Types of mental models by inquiry group and student numbers*

Mental Model	Structured Inquiry Group			Guided Inquiry Group			Student-directed Inquiry Group		
	Pretest	Immediate Posttest	Delayed Posttest	Pretest	Immediate Posttest	Delayed Posttest	Pretest	Immediate Posttest	Delayed Posttest
Initial	0	0	0	0	0	0	0	0	0
Lower Synthetic	4	0	2	7	0	0	0	1	0
Upper Synthetic	39	39	35	41	43	46	44	42	42
Scientific	1	5	7	2	7	4	2	3	4
Total	44	44	44	50	50	50	46	46	46

As seen in Table 4.16, the mean of the Structured Inquiry group on the delayed posttest decreased from the mean on the immediate posttest. The standard deviation increased. Since the minimum score decreased to 28, it fell within the lower synthetic mental model range. The maximum score did not change.

As shown in Table 4.17, the Guided Inquiry group had a total of 50 students: 15 fifth graders, 15 sixth graders, and 10 seventh graders. On the pretest, none of the students were found to hold an initial mental model of the day/night cycle. Seven students held a lower synthetic mental model of the day/night cycle. Their average was 28.29 and they represented 14% of the Guided Inquiry group. Forty-one students were found to hold an upper synthetic mental model of the day/night cycle. Their average was 35.07 and they represented 82% of the Guided Inquiry group. Two students were found to hold a scientific mental model of the day/night cycle on the pretest. Their average was 41.5 and they represented 4% of the Guided Inquiry group.

On the immediate posttest, the Guided Inquiry group had no students holding an initial or a lower synthetic mental model. Forty-three students were found to hold an upper synthetic mental model of the day/night cycle. Their average was 37.26 and they represented 86% of the Guided Inquiry group. Seven students were found to hold a scientific mental model of the day/night cycle. Their average was 41.86 and they represented 14% of the Guided Inquiry group.

As seen in Table 4.16, the mean of the Guided Inquiry group on the immediate posttest increased from the mean on the pretest. The standard deviation decreased. The minimum score increased by five while the maximum score did not change.

Lastly, the Guided Inquiry group had no students found to hold an initial or a lower synthetic mental model of the day/night cycle on the delayed posttest. Forty-six students were found to hold an upper synthetic mental model of the day/night cycle. Their average was 36.85 and they represented 92% of the Guided Inquiry group. There were four students who still held a scientific mental model of the day/night cycle three months after the intervention. Their average was 41.5 and they represented 8% of the Guided Inquiry group.

As seen in Table 4.16, the mean of the Guided Inquiry group on the delayed posttest decreased. The standard deviation decreased. The minimum score increased while the maximum score did not change.

The final Inquiry group was the Student-directed Inquiry group. This group had 46 students: 15 fifth graders, 14 sixth graders and 17 seventh graders. On the pretest, none of the students were found to hold an initial or a lower synthetic mental model of the day/night cycle. Forty-four of the students held an upper synthetic mental model of the day/night cycle. Their average was 34.93 and they represented 95.65% of the Student-directed Inquiry group. Two students were found to hold a scientific mental model of the day/night cycle. Their average was 42 and they represented 4.35% of the Student-directed Inquiry group.

As one the pretest, no students were found to hold an initial mental model of the day/night cycle on the immediate posttest. The number of students holding a lower synthetic mental model of the day/night cycle increased to one. Her score was 28 and she represented 2.17% of the Student-directed Inquiry group. Forty-two students were

found to hold an upper synthetic mental model of the day/night cycle. Their average was 36.76 and they represented 91.3% of the Student-directed Inquiry group. The number of students holding a scientific mental model of the day/night cycle increased to three. Their average was 41.67 and they represented 6.52% of the Student-directed Inquiry group.

As seen in Table 4.16, the mean of the Student-directed Inquiry group on the immediate posttest increased from the mean on the pretest. The standard deviation decreased. The minimum score decreased while the maximum score was unchanged.

As with both prior tests, there were no students found to hold an initial or a lower synthetic mental model of the day/night cycle on the delayed posttest. Forty-two students were found to hold an upper synthetic mental model of the day/night cycle. Their average was 36.6 and they represented 91.3% of the Student-directed Inquiry group. The number of students holding a scientific mental model of the day/night cycle increased to four on the delayed posttest. Their average was 41.25 and they represented 8.7% of the Student-directed Inquiry group.

As seen in Table 4.16, the mean of the Student-directed Inquiry group on the delayed posttest increased from the mean on the immediate posttest. The standard deviation increased. The minimum score and the maximum score did not change.

In summary, inquiry groups did not differ significantly from each other in their mental models from pretest to immediate posttest to delayed posttest. Prior to the treatments, 0%% of the Structured Inquiry group, 0% of the Guided Inquiry group, and 0% of the Student-directed Inquiry group held an initial mental model of the day/night



cycle. 9.09% of the Structured Inquiry group, 14% of the Guided Inquiry group, and 0% of the Student-directed Inquiry group held a lower synthetic mental model of the day/night cycle. 88.64% of the Structured Inquiry group, 82% of the Guided Inquiry group, and 95.65% of the Student-directed Inquiry group held an upper synthetic mental model of the day/night cycle. 2.27% of the Structured Inquiry group, 4% of the Guided Inquiry group, and 4.35% of the Student-directed Inquiry group held a scientific mental model of the day/night cycle.

Immediately after the treatments, 0% of all three inquiry groups held an initial mental model. 0% of the Structured Inquiry group, 0% of the Guided Inquiry group, and 2.17% of the Student-directed Inquiry group held a lower synthetic mental model of the day/night cycle. 88.64% of the Structured Inquiry group, 86% of the Guided Inquiry group, and 91.3% of the Student-directed Inquiry group held an upper synthetic mental model of the day/night cycle. 11.36% of the Structured Inquiry group, 14% of the Guided Inquiry group, and 6.52% of the Student-directed Inquiry group held a scientific mental model of the day/night cycle.

Three months after the treatments, 0% of all three inquiry groups held an initial mental model. 4.55% of the Structured Inquiry group, 0% of the Guided Inquiry group, and 0% of the Student-directed Inquiry group held a lower synthetic mental model of the day/night cycle. 79.55% of the Structured Inquiry group, 92% of the Guided Inquiry group, and 91.3% of the Student-directed Inquiry group held an upper synthetic mental model of the day/night cycle. 15.91% of the Structured Inquiry group, 8% of the Guided

Inquiry group, and 8.7% of the Student-directed Inquiry group held a scientific mental model of the day/night cycle.

As indicated by the student numbers in Table 4.17, 0% of the students held an initial mental model of the day/night cycle prior to the treatments. 7.86% of the students held a lower synthetic mental model of the day/night cycle. 88.57% of the students held an upper synthetic mental model of the day/night cycle. 3.57% of the students held a scientific mental model of the day/night cycle. Immediately following the intervention, 0% of the students held an initial mental model of the day/night cycle. 0.71% of the students held a lower synthetic mental model of the day/night cycle. 88.57% of the students held an upper synthetic mental model of the day/night cycle. 10.71% of the students held a scientific mental model of the day/night cycle. Three months following the intervention, 0% of the students held an initial mental model of the day/night cycle. 1.43% of the students held a lower synthetic mental model of the day/night cycle. 87.86% of the students held an upper synthetic mental model of the day/night cycle. 10.71% of the students held a scientific mental model of the day/night cycle.

#### Qualitative Data Analysis

Another source of information about the students' mental models of the day/night cycle came from the interviews. In each inquiry group, students, selected based on their pretest scores, were interviewed prior to the intervention, immediately after the intervention, and three months after the intervention. Seven of the interviewed students were in the Structured Inquiry group. Table 4.18 shows the how the interview results

compared with the test results. Table 4.19 shows grade and mental models of those students.

Table 4.18  
*Numbers of students indicating correspondence of interview results with test results in three different types of inquiry interventions*

Inquiry type	Pre-interview	Immediate posttest	Immediate post-interview	Delayed posttest	Delayed post-interview
Structured	Correspond = 3 <i>Do not correspond</i> = 1	Change = 2 <i>No change</i> = 5	Correspond = 4 <i>Do not correspond</i> = 3	Change = 1 <i>No change</i> = 6	Correspond = 5 <i>Do not correspond</i> = 2
Guided	Correspond = 6 <i>Do not correspond</i> = 2	Change = 5 <i>No change</i> = 6	Correspond = 4 <i>Do not correspond</i> = 7	Change = 1 <i>No change</i> = 10	Correspond = 5 <i>Do not correspond</i> = 2
Student-directed	Correspond = 1 <i>Do not correspond</i> = 1	Change = 2 <i>No change</i> = 3	Correspond = 2 <i>Do not correspond</i> = 3	Change = 0 <i>No change</i> = 5	Correspond = 5 <i>Do not correspond</i> = 0

Four of the fifth grade students in the Structured Inquiry group were interviewed prior to the intervention. An analysis of the transcripts from their interviews indicated that three held an upper synthetic mental model of the day/night cycle and one held a lower synthetic mental model of the day/night cycle prior to the intervention. Thomas'

Table 4.19

*Students' mental models in the Structured Inquiry group*

Student	Grade	Pre- Interview	Pretest	Post- Interview	Immediate Posttest	Delayed Interview	Delayed Posttest
Susan	5	Lower Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic
Amber	5	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic
Thomas	5	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic
Joseph	5	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic
Seth	6	-	Upper Synthetic	Upper Synthetic	Scientific	Upper Synthetic	Upper Synthetic
Shenifa	6	-	Lower Synthetic	Lower Synthetic	Upper Synthetic	Lower Synthetic	Upper Synthetic
Brigitta	6	-	Upper Synthetic	Lower Synthetic	Upper Synthetic	Lower Synthetic	Upper Synthetic

pretest score of 39, Joseph's pretest score of 34, and Susan's pretest score of 30 also indicated an upper synthetic mental model. Amber, the fourth student, had a score of 40 on the pretest which also indicated that she held an upper synthetic mental model of the day/night cycle. However, Amber's answers on the pretest did not always match the answers she gave in the interview. For example, she had answered question thirteen correctly that the length of day and night change. However, when asked during the interview her explanation was that the only reason for the change was daylight savings time.

Daylight savings time was actually the most common explanation for the change in the length of day and night given by the students during the interviews before the intervention. Three of the four students in the Structured Inquiry group gave this explanation. The fourth, Thomas, explained that it was something in nature and not

human-caused but did not have a complete scientific understanding. As he explained I am “not really sure but I do know that one of the times that it, that time does change, I always know that by Easter.”

Immediately after the interventions, seven students in the Structured Inquiry group were interviewed. In addition to the four fifth graders, three sixth grade students were interviewed. The sixth graders were not interviewed prior to the intervention due to a time issue for the teacher. However, two of the sixth grade students held an upper synthetic mental model of the day/night cycle on the pretest while the third held a lower synthetic mental model of the day/night cycle on the pretest. As shown in Table 4.18, the analysis of their interviews indicated that only one held an upper synthetic mental model of the day/night cycle after the intervention occurred while the other two sixth grade students held a lower synthetic mental model of the day/night cycle.

In her interview immediately after the interventions, Shenifa demonstrated a lower synthetic mental model of the day/night cycle. Her results on the immediate posttest, however, indicated an upper synthetic mental model. Her score increased from 21 on the pretest, which was lower synthetic, to 30 on the immediate posttest. In the interview, she described the Earth as round like a basketball but, when asked to make a model of the Earth out of play dough, made a disc shaped Earth. She also stated that the Earth had an end to which you could walk. This matched her answers on both the pretest and immediate posttest.

Seth, on the other hand, only missed one question on the immediate posttest. However, when asked follow-up questions during the interview it became apparent that

he was often uncertain about his answers and could not always explain them. For example, Seth was asked if the length of day and night changed. His answer was “no, ah, yes...yeah, it does.” When asked how it changed, he answered “I don’t know. It just does.”

As Table 4.17 shows, the analysis of the fifth grade students’ interviews indicated that three students still held an upper synthetic mental model of the day/night cycle immediately after the intervention while the fourth student moved from lower synthetic to upper synthetic. Analysis of Amber’s post-interview indicated an upper synthetic mental model of the day/night cycle, like her prior interview. In her interview, Amber stated that daylight savings caused the change in the length of day and night. This was unchanged from the prior interview. However, this time she said “I don’t know” when asked if there was anything else that make it change besides daylight savings. Before she answered “mmhmm” when asked if daylight savings was the only reason it changed.

Analysis of Susan’s second interview, unlike the first, indicated an upper synthetic mental model of the day/night cycle. Her immediate posttest score was 38, which was eight points higher than her pretest score, still indicated an upper synthetic mental model as well. One of Susan’s misconceptions, like many of the students, had been that daylight savings was the only cause of the change in the length of day and night. After the intervention, she explained that it changed “by different months and days and years” but was not sure about exactly how it changed. Also, prior to the intervention, Susan had stated that at night the sun went “behind the moon” while after wards she

initially gave a more scientifically correct answer that the “Earth only rotates and the sun stays” but when asked follow-up questions admitted that she was not sure whether the sun moved or not.

One interesting side effect of using *Starry Night* was illustrated by Thomas’ responses during his second interview. Both before and after the intervention, Thomas held an upper synthetic mental model. During the first interview, Thomas had indicated that the length of day and night changed but he was not sure of the cause only that “time does change.” Afterward, he stated that day and night occur “by time passing and the...the earth going” and that he figured out that “it is not just the Earth that turns, the sun and the moon have to rotate...kind of rotate, too” He then described the motion of the sun across the sky during the day as shown in the program but was not able to explain the causes behind its motion. In fact, he later said “the Earth does not technically move around in space because if it did that at some point in time probably we’d end up at some...some higher in space and come out of our own atmosphere I think.”

Three months after the interventions, the same seven students in the Structured Inquiry group were interviewed again. Analysis of the transcripts from their interviews indicated that two of the students, both sixth grade girls, held a lower synthetic mental model of the day/night cycle. The remaining five students held an upper synthetic mental model of the day/night cycle. None of the students held either an initial or a scientific mental model of the day/night cycle.

Shenifa’s delayed posttest score of 31, like her immediate posttest score of 30, indicated an upper synthetic mental model of the day/night cycle. However, analysis of

her interview three months after the intervention indicated a lower synthetic mental model. Her answers in the interview did not always match those on her test. For example, Shenifa stated that the length of day and night did not change in her interview. However, when asked that same question on the test she said that it did change due to daylight savings.

Table 4.20  
*Students' mental models in the Guided Inquiry group*

Student	Grade	Pre-Interview	Pretest	Post-Interview	Immediate Posttest	Delayed Interview	Delayed Posttest
Caitlin	5	Lower Synthetic	Upper Synthetic	Lower Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic
Lenny	5	Lower Synthetic	Lower Synthetic	Lower Synthetic	Upper Synthetic	Lower Synthetic	Upper Synthetic
Aubrey	5	Upper Synthetic	Scientific	Upper Synthetic	Scientific	-	Scientific
Anna	5	Lower Synthetic	Lower Synthetic	Lower Synthetic	Upper Synthetic	Lower Synthetic	Upper Synthetic
Isabella	6	-	Upper Synthetic	Upper Synthetic	Upper Synthetic	Scientific	Scientific
Aiden	6	-	Upper Synthetic	Lower Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic
Kira	6	-	Lower Synthetic	Lower Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic
Marco	7	Lower Synthetic	Lower Synthetic	Upper Synthetic	Upper Synthetic	-	Upper Synthetic
Brian	7	Lower Synthetic	Lower Synthetic	Lower Synthetic	Upper Synthetic	-	Upper Synthetic
Theresa	7	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic	-	Upper Synthetic
Brenna	7	Scientific	Scientific	Scientific	Scientific	Scientific	Scientific

As shown in Table 4.20, the Guided Inquiry group had eight students who were interviewed prior to the interventions. Four of the students were fifth graders and four were seventh graders. An analysis of the transcripts from their interviews indicated that



five held a lower synthetic mental model of the day/night cycle prior to the intervention. Only one student, Theresa, held an upper synthetic mental model of the day/night cycle. Brenna, a seventh grader, was the only student in this group to hold a scientific mental model of the day/night cycle.

Brian's pretest score of 26 further supported the conclusion that he held a lower synthetic mental model. An example of a misconception that he, like many others, held was that daylight savings time was the cause of the change in the length of day and night. Two of the seventh graders also gave this explanation. Marco, a seventh grader, indicated that the length of day and night were always twelve hours each as did. Anna, a fifth grader, indicated in her interview that the length of day and night did not change but could not explain why. Ellen, a seventh grader, indicated in her interview that the length of day and night did change but could not explain why.

As shown in Table 4.20, the Guided inquiry group had eleven students who were interviewed immediately following the intervention. In addition to the eight students interviewed before the intervention, three sixth graders, Isabella, Aiden and Kira, were interviewed. Out of the eleven students, six were found to hold a lower synthetic mental model of the day/night cycle based on the analysis of their interviews. Four students were found to hold an upper synthetic mental model of the day/night cycle. Brenna, as before, held a scientific mental model of the day/night cycle.

For three of those students, Caitlin, Lenny and Aubrey, the results from their immediate posttest did not match the analysis of their interviews. According to their scores on the immediate posttest, all three held scientific mental models of the day/night

cycle. Like many of the other students, Caitlin held a misconception about whether the length of day and night changes. On the immediate posttest, she selected yes, due to more than just daylight savings as her answer. However, during her interview immediately after the intervention, she gave a different answer when asked if the length of day and night changed. In that case, she answered no “because there is always 25 days and, uh...ah...24 hours in a day.”

Like Caitlin, Lenny also held a misconception about whether the length of day and night changes. He, too, selected yes, due to more than just daylight savings as his choice on the immediate posttest. However, in the interview he gave two different answers. First, he stated that the length of day and night did not change “because the Earth spins at the same time and the same rate every day.” Later, he stated that it changed “by months, I think” and that “it grows, well, shorter.”

Three months after the intervention, seven students were interviewed to assess their mental models of the day/night cycle. Two of the seven students, Lenny and Anna, were found to hold a lower synthetic mental model of the day/night cycle. Three students, Caitlin, Aiden, and Kira, held an upper synthetic mental model of the day/night cycle. Two students, Brenna and Isabella, were found to hold a scientific mental model.

Unlike the analysis of their interviews, both Anna’s and Lenny’s delayed posttest scores indicated an upper synthetic mental model of the day/night cycle. Lenny, for example, still held a misconception about whether the length of day and night changes. As on his immediate posttest, Lenny selected yes, due to more than just daylight savings as his choice on the

delayed posttest. However, when asked if the length of day and night changed he answered “mmhmm...daylight savings.”

As Table 4.21 indicates, in the Student-directed Inquiry group, there were two students interviewed prior to the interventions. The first was a fifth grade boy, Jason, and the other was a seventh grade girl, Lynda. One, Jason, was found to hold an upper synthetic mental model of the day/night cycle in the interviews. While Lynda scored 42 out of 42 on the pretest, indicating a scientific mental model, the analysis of her interview indicated that she held a lower synthetic mental model of the day/night cycle. She had several misconceptions that came up during the interview. Like the two students from the Guided Inquiry group, she stated that the length of day and night changed but could not explain why. Jason, on the other hand, stated that the length of day and night did not change. When asked why not, he explained that “the earth is always rotating at one am...in one speed.”

Table 4.21  
*Students’ mental models in the Student-directed Inquiry group*

Student	Grade	Pre-Interview	Pretest	Post-Interview	Immediate Posttest	Delayed Interview	Delayed Posttest
Jason	5	Upper Synthetic	Upper Synthetic	Lower Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic
William	6	-	Scientific	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic
Janelle	6	-	Upper Synthetic	Lower Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic
Monetta	6	-	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic
Lynda	7	Lower Synthetic	Scientific	Lower Synthetic	Upper Synthetic	Upper Synthetic	Upper Synthetic

In the Student-directed Inquiry group, five students were interviewed immediately following the intervention. In addition to Jason and Lynda, Janelle, William, and Monetta, all sixth graders, were interviewed. Three of the students held a lower synthetic mental model of the day/night cycle. Two of them held an upper synthetic mental model of the day/night cycle. Interestingly, William had scored a perfect score of 42 on the pretest, which was a scientific mental model. However, on the immediate posttest and the first follow-up interview, he demonstrated an upper synthetic mental model of the day/night cycle. While William described the Earth as a sphere, he selected a fish bowl as model of the Earth, which is not a sphere.

Janelle held an upper synthetic mental model of the day/night cycle on the pretest as well as on the immediate posttest. However, the follow-up interview showed that she held a lower synthetic mental model of the day/night cycle. Like many of the other students, she held a misconception about the length of day and night. While she stated that the length of day and night changed, she was uncertain of the reason. When asked why it changed, she answered “I don’t know...by the speed that the Earth is rotating.” Interestingly, on the pretest, she chose the scientifically correct answer to the question about the length of day and night changing. Yet, on the immediate posttest, she selected the answer that followed from the use of a synthetic mental model.

Immediately following the intervention, Lynda held an upper synthetic mental model of the day/night cycle on both the interview and the immediate posttest. She still stated that that the length of day and night changed but did not know why. Ironically, she

scored a perfect 42 on the pretest while her immediate posttest score of 38 matched the results from her interview.

Prior to the intervention, Jason had stated that the length of day and night did not change. Immediately following the intervention, he gave two different answers to the question. When initially asked, he stated that the length of day and night did not change. However, when asked if the length from sunrise to sunset, for example, changed, he then explained that it did change. The causes behind that change, he explained, were daylight savings time and “the Earth and it always, it sometimes changes speeds.”

All five students were interviewed again three months after the intervention. The five students were found to hold an upper synthetic mental model of the day/night cycle. The results from their delayed posttests also indicated that all five students held an upper synthetic mental model of the day/night cycle.

In summary, in the Structured Inquiry group, no students held an initial mental model, four students held a lower synthetic mental model, thirty-nine students held an upper synthetic mental model and one student held a scientific mental model of the day/night cycle prior to the intervention. Immediately after the intervention, no students held an initial or a lower synthetic mental model, thirty-nine students held an upper synthetic mental model, and five students held a scientific mental model of the day/night cycle. Three months after the intervention, no students held an initial mental model, two students held a lower synthetic mental model, thirty-five students held an upper synthetic mental model of the day/night cycle, and seven students held a scientific mental model of the day/night cycle. However, the interview data did not always confirm the same

mental models as the tests. For example, one of the students who held a scientific mental model on the immediate posttest was found to hold an upper synthetic mental model on the interviews.

In the Guided Inquiry group, no students held an initial mental model, seven students held a lower synthetic mental model, forty-one students held an upper synthetic mental model, and two students held a scientific mental model of the day/night cycle prior to the intervention. Immediately after the intervention, no students held an initial or a lower synthetic mental model, forty-three students held an upper synthetic mental model, and seven students held a scientific mental model of the day/night cycle. Three months after the intervention, no students held an initial or a lower synthetic mental model, forty-six held an upper synthetic mental model, and four held a scientific mental model of the day/night cycle. However, the interview data did not always confirm the same mental models as the tests. For example, six of the students who held an upper synthetic mental model on the immediate posttest were found to hold a lower synthetic mental model in the interviews while two of the students who held an upper synthetic mental model on the delayed posttest were found to hold a lower synthetic mental model in the interviews.

In the Student-directed Inquiry group, no students held an initial or a lower synthetic mental model, forty-four students held an upper synthetic mental model, and two students held a scientific mental model of the day/night cycle prior to the intervention. Immediately following the intervention, no students held an initial mental model, one student held a lower synthetic mental model, forty-two students held a

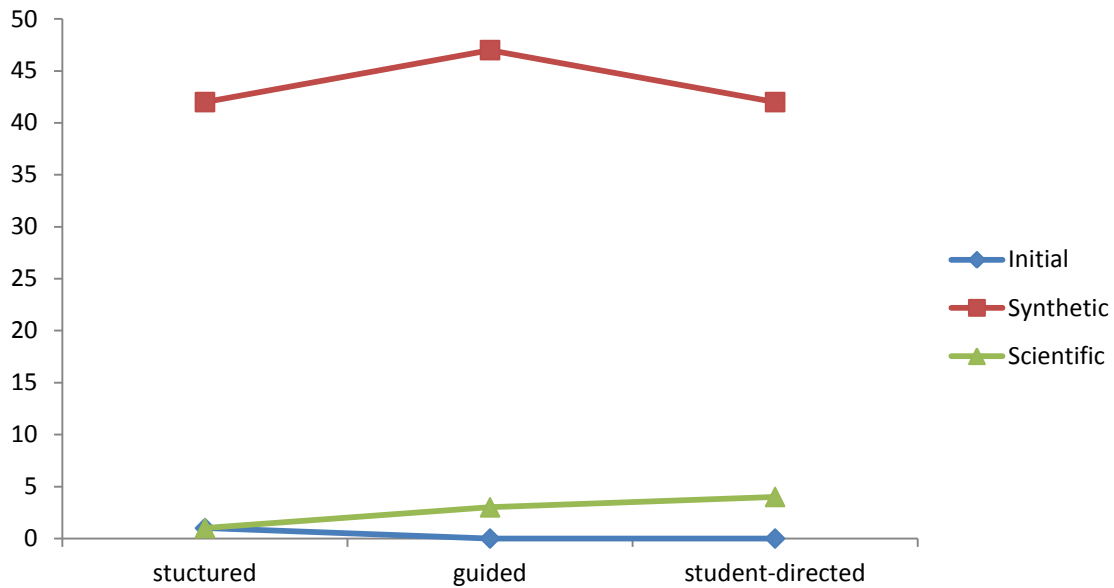
synthetic mental model, and three students held a scientific mental of the day/night cycle. Three months after the intervention, no students held an initial or a lower synthetic mental model, forty-two students held an upper synthetic mental model, and four students held a scientific mental model of the day/night cycle. However, the interview data did not always confirm the same mental models as the tests. For example, three of the students who held an upper synthetic mental model on the immediate posttest were found to hold a lower synthetic mental model on the interview.

### *Research Question 3*

Research question three was: What interaction effect occurs between starting mental model, and inquiry type?

### Quantitative Data Analysis

Looking at Figure 4.5, there was no interaction between starting mental model and the type of inquiry. This was backed up the results of a repeated measures ANOVA where the within subject effects for group\*mental model were  $F=2.309$  with  $p=0.057$ .



*Figure 4.5.* Interaction between starting mental model and type of inquiry.

### *Summary*

In summary, this chapter presented the results from my dissertation study. First, the comparative effects of Structured Inquiry, Guided Inquiry, and Student-directed Inquiry on middle school students' mental models of the day/night cycle immediately and three months following the intervention revealed no statistical difference among the three treatments. Time, however, appeared to have a significant negative effect on students' mental models of the day/night cycle.

Second, inquiry groups did not differ significantly in their mental models. Prior to the treatments, 0% of the Structured Inquiry group, 0% of the Guided Inquiry group, and 0% of the Student-directed Inquiry group held an initial mental model of the day/night cycle. 9.09% of the Structured Inquiry group, 14% of the Guided Inquiry



group, and 0% of the Student-directed Inquiry group held a lower synthetic mental model of the day/night cycle. 88.64% of the Structured Inquiry group, 82% of the Guided Inquiry group, and 95.65% of the Student-directed Inquiry group held an upper synthetic mental model of the day/night cycle. 2.27% of the Structured Inquiry group, 4% of the Guided Inquiry group, and 4.35% of the Student-directed Inquiry group held a scientific mental model of the day/night cycle.

Immediately after the treatments, 0% of the three inquiry groups held an initial mental model. 0% of the Structured Inquiry group, 0% of the Guided Inquiry group, and 2.17% of the Student-directed Inquiry group held a lower synthetic mental model of the day/night cycle. 88.64% of the Structured Inquiry group, 86% of the Guided Inquiry group, and 91.3% of the Student-directed Inquiry group held an upper synthetic mental model of the day/night cycle. 11.36% of the Structured Inquiry group, 14% of the Guided Inquiry group, and 6.52% of the Student-directed Inquiry group held a scientific mental model of the day/night cycle.

Three months after the treatments, 0% of the three inquiry groups held an initial mental model. 4.55% of the Structured Inquiry group, 0% of the Guided Inquiry group, and 0% of the Student-directed Inquiry group held a lower synthetic mental model of the day/night cycle. 79.55% of the Structured Inquiry group, 92% of the Guided Inquiry group, and 91.3% of the Student-directed Inquiry group held an upper synthetic mental model of the day/night cycle. 15.91% of the Structured Inquiry group, 8% of the Guided Inquiry group, and 8.7% of the Student-directed Inquiry group held a scientific mental model of the day/night cycle.

Looking at the interviewed students, 0% of the Inquiry groups held an initial mental model. 25% of the Structured Inquiry group, 62.5% of the Guided Inquiry group, and 50% of the Student-directed Inquiry group held a lower synthetic mental model prior to the intervention. 75% of the Structured Inquiry group, 25% of the Guided Inquiry group, and 50% of the Student-directed Inquiry group held an upper synthetic mental model. 0% of the Structured Inquiry group, 12.5% of the Guided Inquiry group, and 0% of the Student-directed Inquiry group held a scientific mental model.

Again only looking at the interviewed students, 0% of the Inquiry groups held an initial mental model immediately after the intervention. 28.6% of the Structured Inquiry group, 54.5% of the Guided Inquiry group, and 60% of the Student-directed Inquiry group held a lower synthetic mental model prior to the intervention. 71.4% of the Structured Inquiry group, 36.4% of the Guided Inquiry group, and 40% of the Student-directed Inquiry group held an upper synthetic mental model. 0% of the Structured Inquiry group, 9.1% of the Guided Inquiry group, and 0% of the Student-directed Inquiry group held a scientific mental model.

Looking at the interviewed students, 0% of the Inquiry groups held an initial mental model three months after the intervention. 28.6% of the Structured Inquiry group, 28.57% of the Guided Inquiry group, and 0% of the Student-directed Inquiry group held a lower synthetic mental model prior to the intervention. 71.4% of the Structured Inquiry group, 2.86% of the Guided Inquiry group, and 100% of the Student-directed Inquiry group held an upper synthetic mental model. 0% of the Structured Inquiry group,

28.57% of the Guided Inquiry group, and 0% of the Student-directed Inquiry group held a scientific mental model.

Third, there was no interaction between starting mental model and the type of inquiry.

Immediately and three months following the interventions no statistical differences were revealed by the comparative effects of Structured Inquiry, Guided Inquiry, and Student-directed Inquiry on middle school students' mental models. In addition, the three inquiry groups did not differ significantly in their mental models prior to, immediately after, or three months after the treatments. Lastly, there was no interaction between starting mental model and the type of inquiry.

## CHAPTER V

### CONCLUSIONS

This chapter of my dissertation presents a summary of the study that includes 1) the findings from each research question, 2) discussion of what those findings might suggest, 3) limitations of the study, and 4) ideas for future research.

#### *Summary of the Study*

The purpose of this study was to compare fifth, sixth and seventh grade students' mental models of the day/night cycle before and after the implementation of 1) student-directed inquiry activities, 2) guided inquiry activities, and 3) structured inquiry activities using interactive simulation software called *Starry Night Middle School*. Initial mental models are constrained by presuppositions and misconceptions (Vosniadou & Brewer, 1992). Synthetic mental models are formed when students attempt to assimilate their initial mental model with the scientifically correct model (Vosniadou & Brewer, 1992). Synthetic mental models can be divided into lower and upper synthetic (Plummer, Wasko, & Slagle, 2011). Scientific mental models are the culturally and scientifically accepted views (Vosniadou & Brewer, 1992).

#### *Research Question 1*

What are the comparative effects of inquiry types on middle school students' mental models of the day/night cycle immediately following the inquiry intervention and three months later?

### *Findings*

With regard to the comparative effects of Structured Inquiry, Guided Inquiry, and Student-directed Inquiry on middle school students' mental models of the day/night cycle immediately and three months following the intervention, the results revealed no statistical difference among the three treatments. Time, however, appeared to have a significant negative effect on students' mental models of the day/night cycle.

### *Discussion*

Based on the literature (Scallon, 2006; Yager, Abd-Hamid, & Akcay, 2005), I expected to find that the Guided Inquiry would have the best effect on students' mental models of the day/night cycle. However, the findings from my dissertation did not confirm that expectation. So, a teacher selecting which type of inquiry to use in a classroom would, based on my findings, be able to choose one or any combination of treatments and be able to expect the similar outcomes.

While there were no significant differences in the mental models of the students in the three inquiry groups, the means of the three inquiry groups did increase from pretest to immediate posttest. The Structured Inquiry group saw an increase of 3.59 points. The Guided Inquiry group had an increase of 3.91 points. The Student-directed Inquiry group had an increase of 1.65 points. These gains were statistically significant across the three inquiry groups over time. These findings are consistent with the findings of Kangassalo (1993, 1994, and 1997) that inquiry of some kind helps change students' mental models toward the scientifically correct model. The findings were also consistent

with those findings of Hayes, et al (2003), which indicated only modest success in changing children's mental models.

In addition, with standard deviations on the pretest of 4.25, 3.99, and 3.01, the Structured, Guided, and Student-directed Inquiry groups did not differ much from each other before the interventions. With standard deviations of 2.98, 2.76, and 2.86 on the immediate posttest and 3.43, 2.27, and 3.03 on the delayed posttest, the groups did not differ much from each other after the interventions either. These standard deviations also showed that the scores of the students within each group were clustered together on the pretest, immediate posttest and delayed posttest. This may have contributed to the lack of significant differences among the groups.

Looking at effect size further supports the finding that the three groups did not differ much from each other. The smallest overlap for the immediate posttest, 78.7%, was between the Guided and Student-directed Inquiry groups. The highest overlap for the immediate posttest, 92.3%, was between the Structured and Guided Inquiry groups. The overlap between the Structured and Guided Inquiry groups, between the Structured and Student-directed Inquiry groups, and between the Guided and Student-directed Inquiry group for delayed posttest was 92.3%.

The findings also showed that time had a significant negative effect on students' mental models of the day/night cycle. While the number of scientific mental models of the day/night cycle increased immediately after the intervention, the majority of those students reverted back to an upper synthetic mental model of the day/night cycle three months after the intervention. This confirms that misconceptions, which make up initial

and synthetic mental models, can be very robust and, therefore, are hard to correct. In order to circumvent reversion to misconceptions in mental models, regular reinforcement might need to be added to instructional interventions. Further study might explore the extent of reinforcement required for effective interventions.

The findings of Trundle and Bell (2010) were similar to those in my study. There was no statistical difference among their three treatment groups. Trundle and Bell (2010) did find that the *Starry Night*-only group had the highest gains in all cases, which encourages me since, while there were no significant differences among the groups in my study, all three did see gains. Two things in Trundle and Bell's (2010) study were similar to my study: 1) use of computer simulation software and 2) use of guided inquiry. Unlike Trundle and Bell (2010), my study compared three types of inquiry-based learning while their study compared different methods of collecting data. Another difference between my study and Trundle, et al. (2010) was the length of the study: ten weeks (approximately eight hours). The length of my study was one week (approximately 2.5 hours). This leads me to ask: would more instructional time help strengthen my study?

The lack of significant treatment effects differs from the findings of Taylor, Barker, and Jones (2003). Taylor, Barker, and Jones began their mental model-building intervention with 48% of the students holding a scientific mental model. After the four phases of their intervention, 90% of the students held a scientific mental model on both the post survey and the post-post-survey, indicating that mental model-building positively affect mental models. A major difference between the two studies was that in

the Taylor et. al study the students selected one of Jones and Lynch's (1987) five mental models of the Sun-Earth-Moon system prior to the intervention. In addition, their teacher told students about the range of views in the classroom. In future studies, this knowledge would allow the teacher and/or researcher to address specific misconceptions.

This leads to a possible improvement to the study. In future studies, I could have the students compare their mental model of the day/night cycle to the scientific mental model at the beginning of the intervention. Each student's mental model could be determined by the pretest I used in this study.

My findings were a contribution to an area of research that still has a gap that needs to be filled. Many studies have examined how the use of computer simulations affects students' conceptual understandings, and the findings indicate that the use of computer simulations is effective in promoting scientific conceptions (Bell & Trundle, 2006, 2008; Gazit, Yair & Chen, 2005; Plummer, 2011; Trundle & Bell, 2005, 2010; Windschitl & Andre, 1998). However, few studies have specifically examined how interactive simulation software affects students' mental models differentially according to age, developmental level, or grade (Kangassalo, 1993, 1994, 1997, 1999).

Few studies have compared the effects of types of inquiry-based learning with each other across grade levels (Scallon, 2005; Yager, 2005). Other than my study, I have found no studies that compare the effects of structured inquiry, guided inquiry, and student-directed inquiry to determine the most effective balance between instructor and learner control for learning scientific concepts.



*Research Question 2*

What mental models (e.g. initial, lower synthetic, upper synthetic and scientific) do middle school students hold (a) prior to, (b) immediately after, and (c) three months after interventions using one of three inquiry types?

*Findings*

Table 5.1  
*Mental models held by participants*

	Structured Inquiry group			Guided Inquiry group			Student-directed Inquiry group		
	Before	After	3 months after	Before	After	3 months after	Before	After	3 months after
Initial	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lower Synthetic	9.09%	0%	4.55%	14%	0%	0%	0%	2.17%	0%
Upper Synthetic	88.64%	88.64%	79.55%	82%	86%	92%	95.56%	91.3%	91.3%
Scientific	2.27%	11.36%	15.91%	4%	14%	8%	4.35%	6.52%	8.7%

Table 5.2  
*Mental models held by interviewees*

	Structured Inquiry group			Guided Inquiry group			Student-directed Inquiry group		
	Before	After	3 months after	Before	After	3 months after	Before	After	3 months after
Initial	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lower Synthetic	25%	28.6%	28.6%	62.5%	54.5%	28.57%	50%	60%	0%
Upper Synthetic	75%	71.4%	71.4%	25%	36.4%	42.86%	50%	40%	100%
Scientific	0%	0%	0%	12.5%	9.1%	28.57%	0%	0%	0%

*Discussion*

As Table 5.1 shows, the findings confirmed that the researcher was correct to expect that the majority of students would hold an upper synthetic mental model of the day/night cycle both immediately after and three months after the intervention. The

findings also confirmed the expectation that there would be a decrease in the number of students holding a scientific mental model of the day/night cycle three months after the intervention when compared to results immediately after the intervention.

As shown in Table 5.2, the findings from the interviews further confirmed that the researcher was correct to expect that the majority of students would hold an upper synthetic mental model of the day/night cycle both immediately after and three months after the intervention. The findings also confirmed the expectation that there would be a decrease in the number of students holding a scientific mental model of the day/night cycle three months after the intervention when compared to results immediately after the intervention.

Plummer, Wasko, and Slagle (2011) had similar findings with their study. They also found an increase in the number of participants who held scientific mental models immediately after their treatment. However, several differences exist between their study and mine. First, the 16 participants in their study were gifted third graders while my 140 participants were regular education fifth, sixth and seventh graders. Second, 13% of their participants held naive mental models prior to their intervention while none of mine did. Third, they did not conduct a delayed posttest test.

Trundle, Atwood, and Christopher (2007b) also had similar findings with their study. They, too, found an increase in the number of participants who held scientific conceptions immediately after their treatment. However, six or more months later, as in this study, they found a decrease in the number of participants holding scientific conceptions indicating that, in spite of improvements in students' mental models

following treatments, students did not necessarily retain the more correct mental models over time. This would indicate a need for follow-up treatments to reinforce learning gains. It also emphasizes the importance of the delayed posttest and delayed interview in my study.

Looking at students' mental models prior to the intervention, the findings were inconsistent with the findings of Vosniadou and Brewer (1994). In their study, 1 out of 20 fifth grade students held an initial mental model and 11 out of 20 fifth grade students held a synthetic mental model of the day/night cycle. The remaining students had inconsistent mental models, could not explain the phenomenon in question, or gave an explanation the researchers could not understand. In my dissertation study, 0 out of 48 fifth grade students held an initial mental model, 46 of 48 fifth grade students held a synthetic mental model, and 2 of 48 fifth grade students held a scientific mental model of the day/night cycle.

One major difference between the studies was that the students in the study were located in a rural town, while the students in Vosniadou & Brewer (1994) were located in an urban city. The demographics of the two locations were very different (urban city: 67.01% White, 14.34% African-American, 14.24% Asian, and 3.54% Hispanic; rural town: 88.37% White, 4.40% African-American, 0% Asian, and 11.47% Hispanic). One question that remains is if the study had been conducted in a larger city with a more diverse population would the differences amongst the three inquiry groups have been significant.

### *Research Question 3*

What interaction effect occurs between starting mental model, and inquiry type?

#### *Findings*

With regard to an interaction effect, there was no interaction between starting mental model and the type of inquiry.

#### *Discussion*

Findings showed that differences among students' starting mental models (initial, synthetic, and scientific) were constant across the three types of inquiry. Therefore, the overall treatment effect was relevant across the three types starting mental model. Teachers looking to help their students correct their initial and synthetic mental models would be able to choose any of the three types of inquiry and know that the improvement of students' mental models of the day/night cycle would be about the same.

#### *Limitations*

The first limitation was the number of students who participated in my study. Conducting my study in Baltimore, or another large city, would have increased the number of students who participated. Having a larger number of students would have allowed me to run statistical tests, such as multinomial linear regression, that I was unable to run. This leads me to ask what effect a larger participant pool and these tests would have on my findings.

My second limitation was a lack of diversity in scores. As shown by the means and standard deviations, the students in the rural town were relatively high scoring and

there was not much variation amongst the scores. Based on my experience teaching, both in Baltimore and in Texas, I know the same would not be true at a large public school in an urban city, like Baltimore.

A third limitation was the familiarity that rural students had with nature. The rural students had fewer misconceptions, which contributed to their higher scores. Urban students spend less time outside and, with light pollution, are less familiar with astronomy and the day/night cycle in particular. Nature Deficit Disorder, for example, disrupts children's abilities to connect to nature. According to Louv (2008)-who coined the term-Nature Deficit Disorder, it is caused, in part, by the loss of natural surroundings in a child's neighborhood and city. This would be a more common problem in an urban city than in a rural town. This means students in an urban city may have more misconceptions and, therefore, score lower on the pretest,

A fourth limitation was that students were not randomly assigned to the inquiry groups. Each of the three classes stayed intact and was given one of the three treatments. Due to class schedules, this type of random assignment was not possible. Random assignment of students in treatment groups ensures that any differences between and within groups is not systematic at the beginning of the experiment. It does not guarantee that the groups are equivalent but that any differences are more likely due to chance.

A fifth limitation was the length of the study. Having been a teacher, I was aware that making the treatment portion of the study two weeks long, as originally designed, would have created some difficulties. Teachers have many constraints on them in terms of curriculum, testing, etc. Finding teachers willing to give up two weeks of class time to

a study, especially for a graduate student, would have been difficult. Therefore, I was forced to shorten the treatment portion of the study to one week. How this may have impacted the results can be explored in future research studies.

Since I selected *Starry Night Middle School* in the summer of 2006, there are newer options for interactive simulation software. For example, Trundle and Bell (2010) used *Starry Night* and Plummer, Wasko, and Slagle (2011) used *Stellarium* ([www.stellarium.org](http://www.stellarium.org)). Prior to conducting new studies, I will need to research the effects of affordances of newer software.

Looking at the exploratory factor analysis exposed some weaknesses in my pretest. Questions four, seven, twelve, and fourteen were dropped from the analysis due to the estimated variances. Also, question one did not load on any of the three factors. Revising the questions to address these concerns should help strengthen the pretest.

#### *Future Research*

In considering future research, I drew several things from the studies mentioned in the prior section. First, Trundle and Bell (2010) and Trundle, Atwood, Christopher, and Sackes (2010) used a scoring rubric where participants were given scores ranging from 0 to 10 based on the number of scientific elements and alternative components in their conceptual understanding. In both studies, the scores were used in non-parametric statistical analysis. Using a scoring rubric would give my future studies another source of statistical data.

Future research needs to be conducted that replicates this study in a more populated area with a less homogeneous population in order to have a larger sample of

students with a wider range of scores on the pretest. This would allow the researcher to further test the effects of different types of inquiry on learning.

In addition to the two lessons that were used by the Structured Inquiry group during the study, two other lessons were developed during the pilot study. Ideally, I would be able to conduct a two week study that permitted using all four lessons. Realistically, however, it would probably have to be split into two separate one-week treatments, since it would be difficult for teachers to give up two straight weeks of class time due to curriculum requirements and testing.

There are several research questions that I would like to explore in future studies. First, what differences are there, if any, between the mental models of the boys and the girls? This was a research question in the pilot study. Second, what are the comparative effects of structured inquiry, guided inquiry, and student-directed inquiry on grade 5, grade 6, grade 7, and grade 8 students' mental models of the day/night cycle? This was one of the original research questions that were revised due to sample size. Third, how much reinforcement is required to compensate for deterioration of mental models over time?

### *Summary*

This study extended the literature by examining the effects of 1) student-directed inquiry activities, 2) guided inquiry activities, and 3) structured inquiry activities using interactive simulation software on students' mental models of the day/night cycle. The major findings demonstrate that all three treatments promote learning, but that no one treatment is more effective than another. Given a delay following treatment, students'

mental models tended to revert back to previously held misconceptions. In addition, I found that one treatment is not more effective than another based upon students' starting mental models. This demonstrates that the need exists for further research exploring the effects of different types of inquiry on students' mental models of the day/night cycle. The day/night cycle continues to be a difficult concept for many students to understand well enough to explain. It joins the four seasons, Newton's Third Law, and numerous other scientific concepts whose explanations are not intuitively obvious. Improving scientific reasoning and understanding, along with increasing the percentage of students who construct scientific mental models, continues to be a challenge for teachers.



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## APPENDIX A

### LESSONS

Name \_\_\_\_\_

#### Lesson 1: Daylight in the U.S.A

##### Tools from the *Starry Night* toolbar used in this exercise

*Time Controls:* 

*Direction of View Buttons:* 

*Changing Date/Time:* click on month, day, year, hour, minute, second, or AM/PM then use arrow keys.

##### Prior Knowledge Questions:

1. Does the sun always rise in the same place? Yes / No
2. Does the sun always rise at the same time? Yes / No
3. Does the sun's path across the sky change during the year? Yes / No
4. Does the sun always set at the same time? Yes / No
5. Does the sun always set in the same place? Yes / No

##### Exercise 1

###### *Instructions*

- Select viewing location: Waco, TX
- Select time flow rate: 300x
- Use the stop button (■) in time controls in the tool bar to stop motion
- Select date: March 5, 2008
- Select time: sunset

###### *Questions*

1. What time is sunrise?

2. What time is sunset?

3. How long was the day? (Hint: How many hours is it between sunrise and sunset?)

*Instructions*

- Click on the Run time forward button (▶) of the time control. Observe the motion of the Sun.
- When the Sun reaches the top of the screen, click on the south button. Again, observe the motion of the Sun.
- When the Sun reaches the edge of the window, click on the west button. Observe the motion of the Sun. Stop and repeat as necessary.

*Questions*

4. Describe the motion of the Sun as it travels across the sky. (example: In what direction does it move? How high does it get? Does it always rise and set in the same places? You can draw it.)

5. Besides the Sun, what other objects are visible in the sky during the day? (Hint: Look around at sunrise and sunset for planets, stars and/or the Moon)

Exercise 2

*Instructions*

- Select viewing location: Waco, TX
- Select date: select June 5, 2008

- Select time: sunrise
- Select time flow rate: 300x
- Use the stop button (■) in time controls in the tool bar to stop motion

*Questions*

1. What time is sunrise?
  
  
  
  
  
  
  
  
  
  
2. What time is sunset?
  
  
  
  
  
  
  
  
  
  
3. How long was the day? (Hint: How many hours is it between sunrise and sunset?)

*Instructions*

- Click on the Run time forward button (▶) of the time control. Observe the motion of the Sun.
- When the Sun reaches the top of the screen, click on the south button. Again, observe the motion of the Sun.
- When the Sun reaches the edge of the window, click on the west button. Observe the motion of the Sun. Stop and repeat as necessary.

*Questions*

4. Describe the motion of the Sun as it travels across the sky. (example: In what direction does it move? How high does it get? Does it always rise and set in the same places? You can draw it.)

5. Besides the Sun, what other objects are visible in the sky during the day? (Hint: Look around at sunrise and sunset for planets, stars and/or the Moon)

### Exercise 3

#### *Instructions*

- Select viewing location: Waco, TX
- Select date: select September 5, 2008
- Select time: sunrise
- Select time flow rate: 300x

#### Questions

1. What time is sunrise?
2. What time is sunset?
  
3. How long was the day? (Hint: How many hours is it between sunrise and sunset?)

#### *Instructions*

- Click on the Run time forward button (▶) of the time control. Observe the motion of the Sun.
- When the Sun reaches the top of the screen, click on the south button. Again, observe the motion of the Sun.
- When the Sun reaches the edge of the window, click on the west button. Observe the motion of the Sun. Stop and repeat as necessary.

#### *Questions*

4. Describe the motion of the Sun as it travels across the sky. (example: In what direction does it move? How high does it get? Does it always rise and set in the same places? Draw it.)

5. Besides the Sun, what other objects are visible in the sky during the day? (Hint: Look around at sunrise and sunset for planets, stars and/or the Moon)

#### Exercise 4

##### *Instructions*

- Select viewing location: Waco, TX
- Select date: select December 5, 2007
- Select time: sunris8

##### Questions

1. What time is sunrise?

2. What time is sunset?

3. How long was the day? (Hint: How many hours is it between sunrise and sunset?)



### *Instructions*

- Click on the Run time forward button (▶) of the time control. Observe the motion of the Sun.
- When the Sun reaches the top of the screen, click on the south button. Again, observe the motion of the Sun.
- When the Sun reaches the edge of the window, click on the west button. Observe the motion of the Sun. Stop and repeat as necessary.

### *Questions*

4. Describe the motion of the Sun as it travels across the sky. (example: In what direction does it move? How high does it get? Does it always rise and set in the same places? You can draw it.)

5. Besides the Sun, what other objects are visible in the sky during the day? (Hint: Look around at sunrise and sunset for planets, stars and/or the Moon)

### Follow-up Questions:

1. Does the sun always rise in the same place? Yes / No
2. Does the sun always rise at the same time? Yes / No
3. Does the sun's path across the sky change during the year? Yes / No
4. Does the sun always set at the same time? Yes / No
5. Does the sun always set in the same place? Yes / No

Name \_\_\_\_\_

## Lesson 2: Daylight around the World

### Tools from the *Starry Night* toolbar used in this exercise

*Changing Location*: click on Options then click on Viewing Location

*Changing Date/Time*: click on month, day, year, hour, minute, second, or AM/PM then use arrow keys.

### Prior Knowledge Questions:

1. Does the sun rise at the same time everywhere in the world? Yes / No
2. Does the sun set at the same time everywhere in the world? Yes / No
3. If it is daytime in the U.S, is it daytime everywhere else in the world? Yes / No

### Exercise 1

#### *Instructions*

- Select viewing location: Houston, TX
- Select time flow rate: 300x
- Use the stop button (■) in time controls in the tool bar to stop motion
- Select date: March 5, 2008
- Select time: sunrise

#### *Questions*

1. What time is sunrise?
  
  
  
  
  
  
  
  
  
  
2. What time is sunset?
  
  
  
  
  
  
  
  
  
  
3. How long was the day? (Hint: How many hours is it between sunrise and sunset?)



*Questions*

1. What time is sunrise?
2. What time is sunset?
3. How long was the day? (Hint: How many hours is it between sunrise and sunset?)

*Instructions*

- Click on the Run time forward button (▶) of the time control. Observe the motion of the Sun.
- When the Sun reaches the top of the screen, click on the south button. Again, observe the motion of the Sun.
- When the Sun reaches the edge of the window, click on the west button. Observe the motion of the Sun. Stop and repeat as necessary.

*Questions*

4. Describe the motion of the Sun as it travels across the sky. (example: In what direction does it move? How high does it get? Does it always rise and set in the same places? You can draw it.)
5. Besides the Sun, what other objects are visible in the sky during the day? (Hint: Look around at sunrise and sunset for planets, stars and/or the Moon?)



5. Besides the Sun, what other objects are visible in the sky during the day? (Hint: Look around at sunrise and sunset for planets, stars and/or the Moon?)

#### Exercise 4

##### *Instructions*

- Select viewing location: \_\_\_\_\_
- Select time flow rate: 300x
- Use the stop button (■) in time controls in the tool bar to stop motion
- Select date: May 30, 2008
- Select time: sunrise

##### *Questions*

1. What time is sunrise?
2. What time is sunset?
3. How long was the day? (Hint: How many hours is it between sunrise and sunset?)

##### *Instructions*



## APPENDIX B

### INTERVIEW QUESTIONS

1. Describe the shape of the earth.
2. How do you know the earth is...? (use the child's words)
3. If you walked for many days in a straight line, where would you end up?
  - a. Is there an end or an edge to the earth?
4. Here is a picture of a house. Where is the house located?
  - a. Why does the earth look flat in this picture, but you said it was round earlier?  
(If an answer other than round, spherical, etc was given for #1 don't ask)
5. Make me a model of the earth using this play-dough.
6. Show me on your model where you think people live.
7. Pretend this is a child. Show me on your model where she would live if she lived in Australia. Where would she live if she lived in the US?
8. Show me on your model where you think the sky is.
9. In relation to your model, where is the moon located?
10. In relation to your model, where are the stars located?
11. In relation to your model, where is the sun located?
12. Tell me how day and night happen.
13. Does the length of day and/or night change? Why/Why not?
14. Where is the sun at night?
15. How does the sun compare in size to the earth?
16. Does the sun move? Why/Why not?
17. Does the earth move? Why/Why not?
18. Does the moon move? Why/Why not?
19. Where are the stars at night?
20. Where are the stars during the day?
21. Do the stars move? Why/Why not?
22. What are the stars?
23. What is the sun?



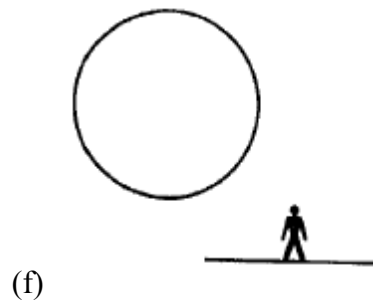
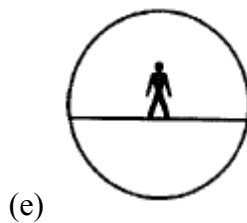
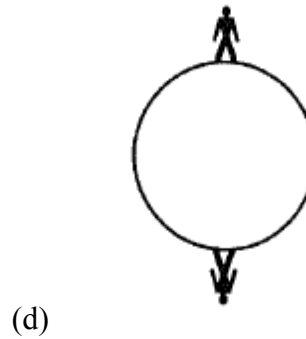
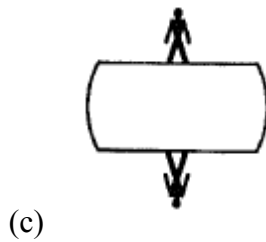
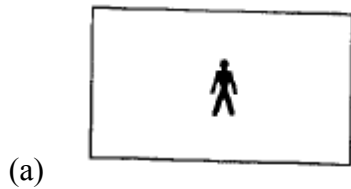
APPENDIX C

PRETEST

1. What do you think the Earth looks like?

- (a) a square tray
- (b) a round tray
- (c) a fish bowl
- (d) a basketball
- (e) a loaf of bread

2. Which of the following drawings do you think shows best the shape of the Earth?



3. If we travel directly eastward, we will eventually

- (a) meet the edge of the Earth
- (b) fall off the edge of the Earth

(c) pass the point where we started

4. Can a person fall off the edge of the Earth?
  - (a) Yes
  - (b) No
5. Is there something that holds the Earth in one place?
  - (a) Yes
  - (b) No
6. Which of the following statements do you think is correct?
  - (a) the Earth orbits the sun
  - (b) the sun orbits the Earth
  - (c) neither the Earth nor the sun move
7. Why does day change into night?
  - (a) the Earth turns
  - (b) the sun turns
  - (c) the sun turns off
8. During the day, the sun
  - (a) shines all over the Earth
  - (b) shines on our side of the Earth only
9. In the sky, during the day, there is
  - (a) only the sun
  - (b) the sun and the stars
10. During the night, the sun
  - (a) goes behind a cloud
  - (b) moves to the other side of the Earth
  - (c) shines on the other side of the Earth
11. When it is day in the United States, it is also day in all the other countries on the Earth.
  - (a) True
  - (b) False
12. For the night to change into day
  - (a) the Earth must turn once around itself
  - (b) the sun must turn once around the Earth
  - (c) the sun must come out from behind a cloud

13. Does the length of day and night change?  
(a) Yes, due to daylight savings only  
(b) Yes, due to more than just daylight savings  
(c) No
14. Does the sun rise at the same time everyday?  
(a) Yes  
(b) No
15. Does the sun set at the same time everyday?  
(a) Yes  
(b) No
16. Do the stars appear to move?  
(a) Yes  
(b) No