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Computer microworld development adapted to children's conceptions : a case study.

Russell L. Couturier
University of Massachusetts Amherst

COMPUTER MICROWORLD DEVELOPMENT ADAPTED TO CHILDREN'S CONCEPTIONS: A CASE STUDY

A Dissertation Presented

by

RUSSELL L. COUTURIER

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RUSSELL L. COUTURIER

Approved as to style and content by:

Howard A. Peelle, Chair

George Forman, Member

Beverly Woolf, Member

Baily W. Jackson, Dean
School of Education

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ABSTRACT

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RUSSELL L. COUTURIER, B.S., SPRINGFIELD COLLEGE

M.S., SPRINGFIELD COLLEGE

Ed.D., UNIVERSITY OF MASSACHUSETTS AMHERST

Directed by: Professor Howard A. Peelle

This research studied changes in ten middle school students' scientific conceptions during interaction with a computer microworld designed adaptively for exploring phases of the moon. Following direct observations of lunar phenomena, five students participated in the development of the computer microworld. The researcher implemented software design requests from the students based on their real world and microworld experience. Five different students used the final revised microworld and provided additional feedback. All sessions were transcribed and analyzed.

Evidence from this case study suggests that this constructionist activity was a good catalyst for inducing conceptual change in learners -- especially the five who had considerable ownership in the software development. Implications for classroom teaching strategies and suggestions for future research are offered.

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INTRODUCTION

1.1 Context

Learning science concepts through lectures, reading, and physical observations removes students from active involvement and makes abstract ideas difficult to understand (Foster, 1996). Science concepts that involve planetary orbits, seasonal changes, and lunar phenomena are commonly misunderstood. A recent study found that the majority of high school graduates could not correctly explain solar concepts associated with seasonal changes and lunar orbits (Bisard, Aron, Francek, and Nelson, 1994). Elementary textbooks often show pictures of the sun, earth, and moon forcing students to imagine concepts from a celestial viewpoint. Students may have trouble converting the "God's eye" perspective associated with textbooks to the "geocentric" perspective we experience as observers on earth when viewing lunar phenomena (Marshal,1996). Utilizing formal learning methodologies, direct observation and analysis of the moon are restricted to distinct time and spatial opportunities limiting a learner's ability to globalize scientific concepts.

Computerized microworlds can assist in bridging the gap between formal learning methodologies and student-centered learning. Rieber (1992) defines computer-based microworlds as a bridge between direct instruction and constructivism. He defines a microworld as a small but complete subset of reality where one can go to learn about a specific domain through personal discovery. A microworld enables learners to interact and experiment with models of objects that may otherwise be inaccessible. Perkins and Unger (1994) describe a particular microworld, called "Thinkertools", that enables students to experiment with balls by varying gravitational and directional forces. Objects and forces can be varied independently with immediate feedback of results. These experiments would be nearly impossible to conduct in the real world where gravity is an omnipresent force. Such a microworld-based environment for scientific concepts that are difficult to understand can potentially benefit learners by allowing for inquiry in a less cumbersome problem space.

Microworlds are often associated with "constructionist" learning(Papert, 1980). One of the main tenets of constructionism is that learners actively construct and reconstruct knowledge from their own experiences in the world (Resnick, 1996). When learners are engaged in building projects, special emphasis is placed on the construction of knowledge. Constructionism asserts that learners are most likely to become intellectually engaged in independent thinking when they are working on meaningful ventures.

Constructionism is an extension of constructivism. Constructivism, derived from Piaget's doctrine that knowledge cannot simply be transmitted to another individual, is a theory of learning and defines knowledge acquisition mainly in cognitive terms. At the heart of contructivism is the idea that learning involves personal constructions of knowledge and is accomplished through the process of equilibration. Assimilation and accommodation arise from the natural tension caused by an individual's need for an organized and ordered world while constantly being confronted with the need to adapt to an ever-changing environment (Piaget, 1970).

Whereas constructivism is a theory of knowledge, constructionism is a theory of learning. Dissimilar from constructivism, constructionism sees an important role for individual action. Essentially, the theory is that learners do not simply absorb ideas, they create ideas. Children are more likely to create new ideas, theories, and hypotheses when engaged in working with external artifacts that have personally meaningful content. Based upon constructionist principles, Harel (1991) conducted a three-month study that engaged members of a fourth grade class one hour per day in the design of a computerized educational application to teach fractions. The students became producers of software as opposed to consumers. Prior to the instructional development, students rarely related the fractions to a world other than pictures of slices or drawings on a piece of paper. The students had not connected their formal school knowledge of fractions with an intuitive commonplace use of fractions. Post-instructional development interviews revealed that students, after experiencing software design with fractions, incorporated fractions as part of their real world.

During the 1980s a proliferation of research was conducted focusing on children's understanding within specific content domains of science (Carmichael, 1990). The ability to recognize children's ideas and scientific conceptualizations has played an important role in pedagogy. What a child is thinking has a crucial bearing on learner teacher interactions, and therefore, determines further learning. Harel (1991) refers to this concept as metacognition and metalearning, the representation of knowledge. Metacognition involves the student's cognitive awareness (thinking about their thinking), cognitive control (reflection), and metaconceptual evaluation (thinking about their own knowledge and grasp of concepts). Adopting a constructivist position on learning enables a better understanding of children's thinking and is, therefore, indispensable to the development and improvement of practices in science education (Johnson and Gott, 1996). Driver and Easley (1978) believe that the clinical interviewing style promoted by Piaget for assessing pupils' development in science could be used by curriculum developers and practicing teachers to understand children's ideas and ways of thinking about a topic in question.

Scientific concepts involving lunar events comprise an ideal topic for a microworld. A microworld enables learners to explore and construct otherwise inaccessible knowledge by manipulating time and space constructs. A learner-centric software development exercise enables students not only to construct comprehension of scientific constructs, but also to participate in the creation of a personally meaningful artifact. It seams logical then to apply a constructivist approach to the development of a computerized microworld based upon learners' metacognitive ideas of lunar concepts.

1.2 Overview of Study

The research methodology consisted of collecting data from children during a computer-based instructional activity and applying the data to the development of a cognitively appropriate microworld. A pilot study was conducted to accumulate data from subjects during a constructionist educational activity involving study of phases of the moon. The data were collected using personal journals and group interviews. The pilot study data, combined with current research data, were used to develop the initial revision of the microworld. Then an iterative development process was implemented using additional subjects to test and refine the software application. Similar to Harel (1991), the microworld development process was the medium for a constructionist learning activity, however, the subjects were the application architects, not the developers.

Utilizing a pilot study, journals, and interviewing techniques, learners' metacognitive processes were researched within a ninety day period. Commonly misunderstood aspects of the "phases of the moon", comprised the curriculum content of the investigation. Children's learning styles, methodologies, reflections, misconceptions, and strategies were categorized and documented.

Subjects participated in multiple opportunities to utilize the software and provide feedback to the developer while reflecting upon their own learning. The microworld entailed a cognitively appropriate learning environment that enabled students to construct knowledge based upon their experiences. The term "cognitively appropriate" is used to indicate environments that are defined from a learner perspective as opposed to an instructor perspective.

1.3 Research Goals

The general research goals of this study were to gather data about learners' conceptions of lunar phases during the development of a cognitively appropriate microworld. The process of learning the subject matter in the pilot study and microworld was the basis for analyzing a child's mental processes over a lengthy period of time. This study analyzed the weekly genesis and maturation of individuals' learning processes and the genesis and maturation of the learners as a whole.

Following are the specific objectives that were addressed in this study:

1. To gather qualitative, descriptive data on learners' theories (conceptions and misconceptions) of lunar phenomena.
2. To provide qualitative, descriptive data of learners' mental representations of lunar phenomena.
3. To provide qualitative, descriptive data of learners' cognitive developments in understanding lunar phenomena.
4. To provide qualitative, descriptive data of learners' conceptions of their own learning.

5. To provide qualitative, descriptive data of learners as software designers.

6. To apply the data gathered in goals one through five to the development of a cognitively appropriate microworld.

7. To utilize feedback from the learner’s interaction of the microworld for further development.

1.4 <u>Research Questions</u>

The following research questions were addressed in this study of children learning phases of the moon.

1. As learners interact with the experimental lunar microworld, what aspects of student cognition can be identified?

2. Which features of the microworld bring about conceptual change in learners?

3. Which design features initiated by learners’ bring about conceptual change?

4. How does the learners ability to pose design features affect conceptual change?

5. What are the patterns and themes of conceptual change?

6. Does the computer enhance a constructionist-based activity for exploring lunar phases?

1.5 Purpose of Study

Although this study involved developing a microworld adapted to children's learning, the main purpose of this study was to describe learners' conceptual change. The microworld was a cognitive vehicle for the constructionist activity, not the endpoint. Using this medium, the researcher attempted to generalize, compare, and contrast individuals and categories of learners, observations, behaviors, and conceptual change as it applied to the development of a microworld. The researcher made an attempt to gather qualitative and descriptive data of learner's cognitive change relating to the previously described goals.

1.6 Limitations of Study

The scope of this study was limited to the following criteria:

1. A testing period beginning in September of 1998 and concluding in April of 1999.
2. A five day pilot study analysis of five seventh grade students attending Tantasqua Middle School in Sturbridge, Massachusetts.

3. A nonrandom sample of 10 seventh grade students attending Greater Falls Middle School in Turner Falls, Massachusetts.

4. The microworld could not exceed the development capabilities of the "ToolBook Instructor" multimedia design application.

5. The knowledge domain of this study was specifically limited to phases of the moon as it pertained to the earth and sun. There were no considerations of other planetary or seasonal phenomena.

6. This study had no control over the external classroom learning environments available to students (parent involvement, Internet access, computer access, etc.).

7. This study had no control over prior learner knowledge of the content domain.

8. This study had no control over learners' prior comfort level with computers.

9. The study was a construction of the researcher and the results may be representative of this construction.

10. Control over the effort made by the children was beyond the scope of this study.

11. The researcher provided the sole analysis of interviews and journal entries.

12. The results of this study can not be applied or generalized to other populations beyond the scope of this study.

1.7 Significance of Study

The study is similar to Harel's (1991) study of children designers in that it describes learner's cognitive progressions over several months and focused on specific knowledge domain. Dissimilar to Harel's research, the design of this study did not require students to develop the software independently. The students, nonetheless, were still the major contributors to the design based upon direct (interviews) and indirect (journals) data collection methodologies. This is significant in that a learner's perception and ideas of learning are not limited by individual programming inabilities. The researcher implemented all student design requests. The students were also given multiple opportunities to reflect on their own learning experiences and design theories through multiple iterations with the microworld.

The content of the study was also significant in that it attempted to document learner's conceptions, misconceptions, and learning strategies as they relate to lunar phases that correlate to design elements of the microworld. The insights into the way children change their ideas using constructionist-based activities can be applied to conventional science curriculums.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Overview

This review of literature consists of three major areas: scientific misconceptions, constructionism, microworlds and conceptual change, plus a summary.

2.2 Scientific Misconceptions

2.2.1 Lunar Misconceptions

Learning science through reading or lectures can make abstract ideas difficult for students to comprehend. Compounding this problem is the premise that students frequently enter the classroom with tenaciously held beliefs about the natural world that are contrary to the accepted views of science (Sadler, 1992; Schoon, 1992). Bisard, Aron, Francek, and Nelson (1994) conducted a comprehensive study of scientific misconceptions that surveyed 708 students. The students' educational levels ranged from middle school to college. Question six of the survey dealt specifically with moon phases:

6. The different shapes of the moon (or phases) are caused by:

a) clouds on earth.
b) the earth's shadow.
c) viewing the selected sunlight off the moon.*
d) the varying angle of the sunlight off the earth.

* correct answer

More than sixty percent of respondents answered the question incorrectly. Surprisingly, no significant differences were found when comparing the correct number of responses between middle school, high school, college freshmen, and college seniors. These findings suggest that increasing education does little to dismiss the geocentric attitude that the earth, rather than the sun, is the primary cause of lunar phases. The results of the study suggest that the majority of students confuse lunar eclipses with lunar phases and believe that the earth casts a shadow obscuring a portion of the moon. A minority of students believed that the surface of the moon is obscured by sunlight reflecting off the earth or clouds.

Schneps (1989) produced a film, "A Private Universe," which showed that both Harvard graduates and gifted high school students displayed serious misconceptions about phases of the moon. Similar to the previous study, the film producer documented many instances where participants believed that the phases were caused by the earth's shadow on the moon. Marschall (1996) suggested that the problem may stem from textbook illustrations that show a view of the moon in orbit around the earth with the sun off to one side. Students may have trouble converting mentally from a "God's eye" perspective into a "geocentric" perspective, which is experienced as an observer on the earth looking at the moon. Foster (1996) also supported this notion by stating that elementary science textbooks that use pictures and diagrams of the earth, sun, and moon, force readers to imagine the phenomenon from an outer space viewpoint. External diagrams of the relationship between the earth, sun, and moon, often appear to show all three to be in the same plane, supporting the misconception of the earth casting a shadow upon the moon.

Foster (1996) and Marschall (1996) offer similar classroom modeling activities that promote an "earth centered" view, in an attempt to overcome students' previous misconceptions of lunar phases. A styrofoam ball (the moon) is placed at the end of yardstick and held at eye level in a dark room. A bright light (the sun) is stationed at a fixed point in the room. By revolving in place, the student can observe the different phases of the moon. Students observing the activity from different locations can gain other perspectives, in particular, of this phenomena as if they were standing on the moon or on the sun.

In a study of younger children, Shapiro (1994) found that children believe that the moon is self illuminating, disregarding the effects of sunlight. Children believe that the moon is "half lit" at the one-quarter and three-quarter phases. One analogy made by a child compared the moon to a light bulb, believing that it would burn you in a similar fashion if touched. Apparently, the child's past experiences with light bulbs formulated the rationalization of lunar phenomena.

2.2.2 Light and Shadow Misconceptions

Anderson and Smith (1986) investigated light and shadow misconceptions of fifth and six graders following a formal instructional period. A test containing 37 questions was administered with open ended questions calling for drawings and explanations. The following four topics were covered in the exam:

1. How people see.
2. The nature of color vision.
3. The interaction of light with various objects (transparent, translucent, opaque, and mirrored objects.
4. The structure and functioning of the human eyes.

The results from clinical interviews of a subsample of the test population revealed that the theories of the students tended to be closely tied to sense experience and to specific casual relationships on a phenomenological level whereas scientists were much more likely to invoke invisible mechanisms. The study suggests that children commonly lack these theoretical commitments so they specify cause-effect relationships (turning a light on makes objects in the room bright) without considering the indirect mechanism that might explain this relationship. The researchers also suggested that children tend to recognize many contextual distinctions that scientists regard as irrelevant. Children recognize light passing through glass and people seeing through glass as two distinct phenomena, whereas a scientist views these as similar mechanisms. Scientists tend to develop theories with internal coherence and logical consistency. Children are more likely to invoke ad hoc explanations without considering the implications of their explanations for similar situations.

Fahrer and Rice (1988) conducted a study in which they interviewed 40 children observing light and shadow concepts. Light emitting from a cross-shaped fluorescent source was passed through pinholes and obstructed by small spheres producing varying shadow effects. Questions such as, "What is a shadow?" and "Is there a shadow in the dark, where there is no light?" were posed to the subjects.

Approximately one-quarter of the children interviewed had a clear conception that a shadow is the absence of light. Most children perceived a shadow as a presence that has material characteristics. They believed that shadows have well defined shapes, occupy space, and are capable of motion and of being pushed.

Piaget (1930) documented that children 5 to 9 years of age also think of a shadow as a material that emanates from the object and has independent motion. Older children understand that there is a strong relationship between shadow and light, but they also believe that a shadow exists in complete darkness. The children in the study held a strong belief that a shadow belongs to an object. They believe that during the day, sunlight provokes the object to emanate it's shadow, however, at night the shadow is hiding. The majority of children's experiences with shadows result from objects that are distant from the light source and close to the reflection. In this case, the shadow closely resembles the light source.

2.2.3 Addressing Learner Misconceptions

A common physics misconception among students is the belief that stationary objects do not exert forces on external objects, such as a book resting on a table. Brown and Clement (1989) suggested the use of an anchoring system using analogies to overcome learner misconceptions. In the case of the book and table, they suggested that the student consider a book resting on a spring. The student would concede that the spring compresses and exerts an upward force to return to it's original position. The student was then asked to consider a book resting on a flexible table. The student usually conceded that the table also exerted an upward force to return to the original position. Finally, the student was asked to explain the difference between a flexible table and a rigid table. Brown and Clement (1989) offer the following four steps for overcoming learner misconceptions:

1. A usable anchoring system conception must be present.

2. An anological connection between an anchoring example and target situation should be developed explicitly through the use of intermediate analogies.

3. Engage the learner in a process of interactive teaching and analogical reasoning.

4. Require the learner to construct a new explanatory model of the target situation.

In an earlier study, Brown and Clement (1987) compared two teaching strategies that addressed scientific learner misconceptions. The first method involved concrete illustrations of abstract principles using everyday examples. The second method led the learner through a connected sequence of analogies beginning with an anchor as described in their previous study. When students were presented with multiple examples illustrating an abstract principle, most refused to accept a conclusion that they found counterintuitive. Conversely, when students were presented with a sequence of bridging analogies, they did not hesitate to rescind an earlier misconception. Three reasons emerged from the examination of the data as possible explanations for the differences in student reaction to the methodologies:

1. The anchoring examples to the students must make sense to the learner, not just the instructor.

2. Analogical relationships that are obvious to the instructor need to be explicitly developed for the learner.

3. Create qualitative models that provide mechanical explanations for phenomena.

In a study of learner misconceptions of biological adaptations, Clough and Woods-Robinson (1985) suggested several methodologies for addressing science misconceptions. Teachers should implement a learner-oriented methodology as opposed to a typical structured lesson plan. The instruction should start with learners' ideas beginning with known and familiar concepts and working through concrete examples that conflict with the misconceptions. These ideas should be discussed in small groups allowing for opportunities to talk through scientific explanations and phenomena. Group findings should be explored at the classroom level.

In a three year study that focused on effective strategies in dealing with learner misconceptions, Luallen and Leonard (1990) found support for many of the methods previously cited. An additional method, concept mapping, was introduced to assist learners in making sense of science concepts. A mass activity was suggested where students created a list of all the concepts they could think of that are related to the science topic. Individual, group, and classroom concept maps were constructed. The maps were then used to relate and review similar analogies addressing common misconceptions. Concept mapping resulted in the student connecting basic science concepts to the ideas and mentally constructing meaning.

2.3 Constructionism and Microworlds

2.3.1 Constructionism

One of the main tenets of constructionism is that learners actively construct and reconstruct knowledge out of their own experiences in the world (Resnick, 1996). Special emphasis is placed on the construction of knowledge when learners are engaged in building projects. Constructionism is a theory that argues that learners are most likely to become intellectually engaged in independent thinking when they are working on meaningful ventures. Constructivism is derived from a theory of learning which defines knowledge acquisition in cognitive terms; whereas constructionism sees an important role for affect. Essentially, the theory is that learners do not absorb ideas, they create ideas and are more likely to create new ideas, theories, and hypotheses when engaged in building an external artifact (robot, program, experiment) that has personally meaningful content and comfort.

Constructivism is derived from Piaget's doctrine that knowledge cannot simply be transmitted to another individual. At the heart of contructivism is the idea that learning involves personal constructions of knowledge and is accomplished through the process of equilibration. Assimilation and accommodation are used to operate on the natural tension caused by an individual's need for an organized and ordered world while constantly being confronted to adapt to an ever changing environment (Piaget, 1970). Knowledge must be constructed individually, based on learners' perceptions and interpretations of information, whether received via an instructor, play, or personal experimentation. When teachers are actively conveying material to learners, each student is reconstructing a personal version of the information. Constructionism has the connotation of a construction set starting with sets in the literal sense, such as LOGO, and extended to include programming languages, and activities such as baking (Papert, 1993). Artifacts such as buildings, programs, and recipes are constructed from these sets creating a concrete knowledge of structures, planning, and fractions. One of Papert's main proposals posits that construction that takes place in the mind often happens felicitously when supported by construction of a more public sort in the world (cake, program, LOGO house). Papert's reference to "world" refers to artifacts that can be shown, referenced, touched, examined, and described. Constructionism attaches special importance to the role of construction in supporting the cognitive developments taking place in the learner. One could view constructivism as a theory of intellectual development and constructionism as a theory of education.

Piaget's theory of intellectual development is divided into three basic stages that approximate three timetables of formal education (Ginsburg & Sylvia, 1988).

- The first stage, sensorimotor, approximates preschool age children. Learners can only respond to their immediate surroundings and situations.

• The second stage, concrete operations, approximates the elementary school years. This is a period of concrete logic where knowledge and thought transcend the immediate circumstances. However, learners are not capable of establishing universal operations or general theories based upon experiences. Their methods are tied to the immediate situation.

• The third phase which usually occurs during the adult life is the formal stage. Principles of logic, induction, deduction, and hypothesis testing formulate and govern thought. At this stage a generality of principles have developed.

Papert (1993) differentiates between instructionism and constructionism by pointing out that the educational implications of Piaget's theories of learning are reversed. That is, educators often rush to teach the theories and general principles of science without allowing learners to experience concrete processes. Rather than pushing children to "think like adults," educators might do better to remember that they are legitimate learners and to try harder to be more like them.

Papert (1980) introduces the term "bricolage" as an example of the science of the concrete used by children. Different from analytical science that explains and interprets the universe in generalities, brocolage entails a "use what you have" mentality. Mental tools and structures are used, reused, and improvised as a methodology for intellectual activity. Papert offers a parallel between kitchen math and school math. Cooks who cannot multiply fractions or understand the balancing of equations can readily manipulate fractional ingredients and ratios. Analytic principles such as multiplying fractions are routinely taught in school with direct instruction and are "unconnected" to the real world. Papert uses the term "bricoleaur" to denote making, fixing, and improving mental constructions through concrete operations. Learners use the mental tools of the moment to create new and more sophisticated tools of the future. It is this continuation of the familiar into the new that brings about the idea of scientific principles and generalities that govern the universe. Constructionism and the use of microworlds are conducive to the skills of bricolage.

2.3.2 Microworlds

Rieber (1992) defined computer based microworlds as a bridge between direct instruction and constructivism. He defined a microworld as a small but complete subset of reality where one can go to learn about a specific domain through personal discovery. Rieber differentiates a microworld from a simulation using two essential characteristics. First, a microworld embodies the simplest model of a domain that is deemed accurate and appropriate by an expert. Second, it offers an initial point of entry that matches the user's cognitive state so as to allow fruitful interactions to take place. Papert (1980) suggests that microworlds should have four characteristics: simple, general, useful, and syntonic.

- Simplicity refers to both the ease of use and specificity of domain content.

- The concept of a multipurpose tool is what Papert is referring to as general (such as LEGO bricks that can be used to build a variety of objects).

- Usefulness refers to the applicability of the subject matter to educational goals.

- Syntonic learning means "it is connected to" and suggests that learning is made up of connections, such as new ideas with the old.

Vygotsky (1978) developed a theory of intellectual development defined by the "zone of proximal development" where individuals on the threshold of learning are often unable to create a new meaning without external assistance. Rieber (1992) suggested that microworlds conform to Vygotsky's concept by providing an external intervention to the attainment of a higher level of understanding. The concept of a microworld is a good vehicle for focused exploration of a content domain that allows generalized experimentation and exploration. Resnick (1996) also emphasized a strong relationship between design and learning. Microworlds provide a rich learning environment that allows students to design, construct, and program meaningful artifacts. The next section of this review focuses on research describing the design, construct, and programming qualities of microworlds which facilitate the meaningful construction of knowledge in learners.

2.3.2.1 Microworld Design

Harel (1992) conducted a three-month study that engaged members of a fourth grade class one hour per day in the design of an educational application to teach fractions. The students were assigned to teach "something" about fractions to their peers using LOGO as the development tool. The details and focus of lessons were left entirely up to students (as peer teachers). The students became producers of software as opposed to consumers. Harel interviewed the students prior to the daily activities asking a simple question, "What is a fraction?" In almost all cases the students responded with statements that focused on "a part of something, not a whole." The students rarely related the fractions to a world other than pictures of slices or drawings on a piece of paper. The students had not connected their formal school knowledge of fractions with an intuitive common place use of fractions.

Harel (1992) required the students to keep journals of their ideas and designs while monitoring and observing daily progress. There were as many different approaches and designs to the software as students.

The study greatly detailed the progress of the students. Post interviews revealed that students, after experiencing software design with fractions, incorporated fractions as part of their "real world." They spoke of fractions as twenty-five cents, half-price, weekends, and a school-day. Papert (1993) quoted one student as saying "Why are you bothering me to give you examples of these fractions; don't you see that anything you think of can be an example of a fraction?"

Papert (1993), Harel (1992), and Kafai(1996) believe that when children become software designers with individually defined goals, the project has a personally meaningful undertaking capable of mobilizing intellectual energy. The students take an entirely different approach when compared to completion of daily assigned tasks.

2.3.2.2 Microworld Programming

Resnick (1994) recently compiled a series of studies in his book, *Turtles, Termites, and Traffic Jams*, where students investigated slime mold, termite ecology, and traffic patterns using StarLogo. StarLogo enables thousands of turtles to be programmed and to perform actions simultaneously, simulating complex environments. The turtles interact in spaces called patches that can also be programmed to react to events and to store vital information. An event may be the presence or absence of a turtle, and the patch may record the number of turtle events or keep track of food sources. This allows the environment to have an equal and active status with the interacting objects (turtles). Resnick believes that StarLogo provides a microworld that enables people to think differently about object-environment interactions. He refers to this as stimulation in addition to simulation.

Resnick (1994) designed and conducted a study where students programmed cars (turtles) to follow a predefined route using the following two rule sets.

Rule Set 1	**Rule Set 2**
• If (too close to car in front) then slow down. • If (too far from car in front) then speed up. • If (detect radar) then slow down.	• If (too close to car in front) then slow down. • If (too far from car in front) then speed up.

Students predicted that only set 1 would cause a traffic jam under moderate to heavy traffic. To the surprise of the students, both sets created traffic jams producing nearly similar results. StarLogo provided the students with the tools to think about the problem in a way that was previously impossible.

Resnick's pedagogical intentions are clear and noteworthy. The goal of StarLogo is to probe, challenge, and disrupt the way people think about complex problems. Sperry (1995) states, "The major challenge for educators and educational developers is to create tools and environments that engage the learners in construction, invention, and experimentation. Educators need to introduce tools and problems that allow students to design things." Resnick believes that StarLogo provides the environment for learners to become personally and passionately involved in the dynamic construction of knowledge.

2.3.2.3 Microworld Development

Papert (1993) described the project of a fourth grade student who visited the LEGO-LOGO lab at MIT. The subject was interested in constructing a robot that would move by vibration. The fourth grader had witnessed a washing machine vibrate across the floor after the load had become unbalanced. This observation became the catalyst for his new invention. Initially, the subject experimented with vibration by violently swinging his arm about his body. The subject realized that this swinging created an apparent random motion of his body to compensate for his arm movements. He applied this design to his robot.

The first prototype involved an "arm" attached to a motor secured to the top of a platform with stilt-like legs. This prototype literally self destructed from the vibration. The subject then considered two courses of action: reduce the vibration or increase the strength of the structure. The latter idea produced a structure that was too heavy for the robot to move. The former resulted in a very simple compact design that actually moved on the first test but quickly toppled over due to the vibration. The subject conversed with other classmates and decided to put "shoes" on the stilts by connecting tires with rims facing the floors. There was doubt from the classmates whether this was cheating as it was supposed to be a "wheel-less" robot. The subject resolved this doubt by proclaiming that they were only wheels by definition, but not by function. The "shoes" worked as planned and the subject quickly began a new strategy for steering his robot.

The subject did not follow a predefined plan, but did have a self defined goal with a commitment to realize it. The concept of bricolage as defined by Papert (1980) and Turkle (1984) is at the center of this observation. The subject used the mental and physical tools at his disposal, creating a robot not defined in his initial plans. Utilizing these "tools," the subject discovered, through experimentation, the concept of stability.

2.3.2.4 Experts and Incidental Learning

Daily experts and incidental learning are often integral components of constructionist-based learning environments utilizing microworlds. In all of the works cited (Resnick, 1994; Papert, 1993, 1980; Harel, 1992; and Turkle, 1984), the observations described students that become "experts of the moment" by discovering a new or different use of a tool that peers have yet to discover. In many cases, typically quiet students are encouraged by their peers to describe their discoveries in detail. These "inventors" are elevated for the moment enjoying a position of authority previously attainable by only the teacher or selected classmates. This newly acquired position often acts as a catalyst for the learner to discover new inventions.

Rieber (1993) states that learning does not necessarily flow from a fixed sequence of ideas. Using LOGO, mistakes often lead to new discoveries and interesting phenomena causing the learner to abandon initial projects in favor of projects that focus on the unexpected results. The instructor should be careful to anticipate and nurture incidental learning while maintaining a focus of the original goals. The syntonic nature of microworlds supports the idea of connected learning, merging new ideas with old to create new knowledge structures.

2.3.2.5 Microworlds and Conceptual Change

Perkins and Unger (1994) investigated the following scientific and mathematical microworlds to see if certain types of representations might help students reach better understandings of the respective concepts:

ThinkerTools A microworld used to examine the relationship between force and motion.

WiserTool A microworld used to foster the differentiation between of heat and temperature.

GreenGlobs A microworld used to examine geometric relationships.

The researchers concluded that these microworlds led to better conceptual understandings by facilitating the learner's construction of explanations, justifications, predictions, and confronting misunderstandings.

The relationship between force and motion is a difficult subject matter for students (White, 1984, 1993). Students adopt strong notions that objects receive a particular amount of force that dissipates over the course of travel. Students also tend to believe that new forces simply override the current velocity, completely ignoring momentum. ThinkerTools, developed by White and Horwitz

(1988), is designed to directly address these misconceptions. ThinkerTools allows learners to apply forces (upward, downward, left, and right) to a dot (representing any object) in a frictionless and gravitationless world. A cross displays the cumulative forces that have been applied to the dot. A wake of smaller points trailing the ball indicates the velocity and direction. Students are generally amazed when the dot does not proceed in the direction of the last force applied. Thinkertools allows students to test their intuitive ideas about the influence of force on objects, see the additive effects of discrete and continuous force, and seek alternative explanations for the slowing of objects in a real world.

Wiser and Kipman (1988) developed a computer based microworld to help foster the differentiation of heat and temperature. Objects of varying sizes (mass) are created that contain dots representative of the total amount of heat (energy) of the object. Students can observe an object with twice the mass of another object with equivalent energy will be half the temperature. Students have the ability to vary mass and energy observing the relationship between heat and temperature. The more concrete visualizable dots and objects substitute for the abstract notions of heat, temperature, and molecular energy.

Dugdale and Kibbey (1986) created a computerized graphing tool, Green Globs, that allows students to explore functions in a playful atmosphere. Green globs are randomly placed on a Cartesian coordinate system and students are required to create as few functions necessary that intersect them all. Students must analyze linear and curvilinear functions in relation to the patterns of globs to best service their needs. A similar application, Function Analyzer, allows students to tweak or fiddle with the function without rewriting the entire equation (Harver and Goldberg, 1988). In both applications, the learner is allowed to explore the relationships between symbolic notation and graphic form in an open environment.

There is significant empirical evidence to support the use of microworlds as a constructivist activity to overcome learner misconceptions. White and Horwitz (1988) reported that six graders exposed to the ThinkerTools environment significantly outscored a high school control group and a high school group of students that had recently finished a unit on Newtonian mechanics. In a similar study, Wiser and Kipman (1988) found that 100% of the participants that used the heat and temperature model were able to provide explicit definitions that differentiated heat and temperature compared to 40% of the non-participants. In another qualitative study, Dugdale (1992) observed that students using function analyzers demonstrated a greater facility with the relationships between functions, equations, and graphical representations.

Following an extensive review of the above microworlds, Perkins and Unger (1994) attributed the conceptual change of learners' representations to three principles. First, a microworld reduces the cognitive load by minimizing variables and quickly duplicating similar experiments. These representations allow more freedom to inquire in a less cumbersome problem space. Reducing the number of variables allows a learner to clarify cause-effect relationships without attention to extraneous information. Secondly, a microworld reveals immediate implications to learner hypotheses'; students can quickly examine similar mental constructions over different scenarios in a short amount of time. Thirdly, a microworld provides effective imagistic analogies. Perkin and Unger (1994) refer to a microworld as embodying stripped constructed visual analogs.

> They are analogs in offering analogical representations of the target domain; constructed in that they are made up for that purpose, rather than borrowed from an existing domain; stripped in that they omit potentially distracting and misleading detail; and visual, harnessing the most powerful of the sensory modalities.

2.4 Summary

Learning science through reading or lectures with direct interaction with the medium can make abstract ideas difficult to comprehend. Compounding this problem is the fact that most students frequently enter the classroom with tenaciously held beliefs about the natural world, some of which are contrary to the accepted views of science. Anchoring systems, progressive analogies, and qualitative models that provide mechanical explanations for phenomena have attained varying levels of success in addressing science misconceptions. Microworlds can be viewed as a bridge between direct instruction and constructivism where one can learn about a specific domain through personal discovery by facilitating the learner's construction of explanations, justifications, predictions, and confronting misunderstandings. Microworlds are particularly effective learning tools in domains where students cannot directly experience, manipulate objects, or require accelerated time environments. Frictionless environments, weightlessness environments, and lunar phenomena are examples of this.

Misconceptions associated with lunar phases are often quoted in the science literature and commonly attributed to learners believing that the earth is casting a shadow upon the moon. Learner misconceptions involving light and shadows are rarely discussed as a contributing factor to the difficulty in learning this subject. A microworld based upon learner misconceptions, conceptions, and qualitative models using anchoring systems, analogies, and constructivist learning methodologies would be a significant contribution to this knowledge domain.

CHAPTER 3

METHODOLOGY

3.1 Overview

The research methodology consisted of collecting data from children during a computer based instructional activity and applying the data to the development of a cognitively appropriate microworld. A pilot study was conducted to accumulate data from subjects during a constructivist educational activity involving study of phases of the moon. The data were collected using personal journals and group interviews. The pilot study data, combined with current research data, were used to develop the initial revision of the microworld. Then an iterative development process was implemented using additional subjects to test and refine the software application. The research study consisted of the following three phases:

<u>Pilot Study</u> Through formal and informal methods, students constructed their knowledge of lunar phenomena to assist in the initial development of the microworld.

<u>Analysis and Design</u> Students used the microworld based on pilot study data providing critical feedback to the researcher through a clinical interviewing process. Discussion of design instructional elements was

included as development criteria for the next iteration of the microworld.

Cognitive Tool Students interacted with the final version of the microworld developed in the previous stage. Design elements were not altered for this group.

3.2 Subjects

Five seventh grade male and female students from the Tantasqua Middle School located in Sturbridge, Massachusetts were used for the pilot study. Ten seventh grade male and female students from the Greater Falls Middle School located in Turner Falls, Massachusetts and the Tantasqua Middle School located in Sturbridge, Massachusetts were used for the formal study. A non-random selection process based upon student availability and volunteers assigned these students to the pilot and research groups from an available pool of approximately sixty students.

3.3 Pilot Study Procedures

A three-week pilot study was conducted to gather preliminary data on subjects learning about phases of the moon. A personal journal was provided to all students for lunar observations, drawings, and self-learning compositions (see Appendix A for an example). All subjects observed the moon each night for a period of two weeks. The subjects recorded the date, time, and visual representation of their observations in their personal journals. Directions to the subjects at the beginning of the observations stressed that their drawings should be "scientific" paying particular attention to the size, shape, color, and height of the moon in the sky. The learners were encouraged to observe the moon at different times on the same night and at different times on different nights. Figure 3-1 is an example of a nightly observation.

Day 23 Date: 02/12/98 Time: 9:30 PM

Figure 3.1: Observation Sheet

To avoid poor weather affecting the subject's consistency in recording lunar behavior, the researcher provided a lunar calendar for the current and proceeding month. Students were told to use this chart only if lunar observations were unobtainable due to weather or family obligations. Following the two week observation period, the researcher posted a chart showing lunar observances for the following six weeks. Subjects were encouraged to continue observing the moon, but were not required to. The subjects were given one hour to write about their observations and theories in their personal journals in a group session. The researcher was available during this time to help the students formulate their ideas.

3.3.1 Constructivist Teaching Activity

During week three, the subjects participated in the following instructional programs to examine their initial theories concerning lunar observations. The activities were not designed to teach students about lunar phenomena, but rather, to allow students to construct their own knowledge through hands-on activities. Conceptions, misconceptions, and theories were investigated through group activities. Time at the end of each activity allowed students to reflect on their learning through personal journals.

Look to the Moon A "hands on" exercise described by Foster (1996) was utilized by the researcher. Subjects mounted a small Styrofoam ball on the end of a meter stick. Standing in a darkened room, students held the meter stick near their nose and pointed it toward the ceiling at a 45 degree angle. The researcher held a table lamp with the shade removed in the middle of the room representing the sun. The subjects turned themselves in a circular motion, providing a line of sight similar to actual moon observations from the earth. A variation of the above activity was also used. Learners placed different shaped objects (balls, cones, cylinders, cubes) in the center of a darkened room with an external light source providing the ability to see multiple objects from different perspectives by moving about the room. Figure 3.2 contains an illustration of each activity.

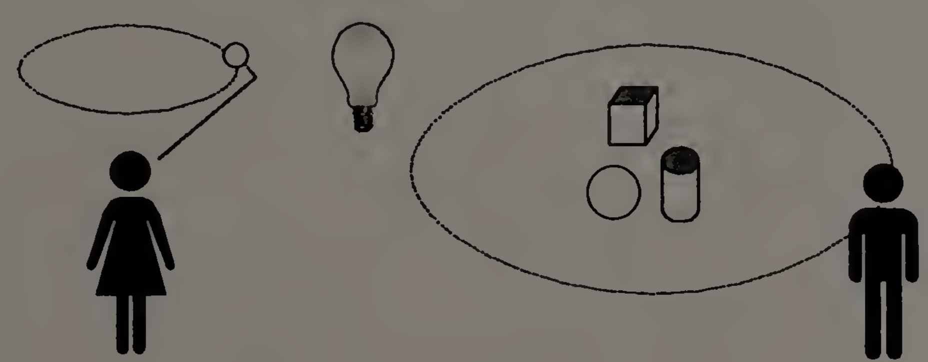


Figure 3.2: Constructivist Activities

3.3.2 Microworld Design Revision 1.0

One 90-minute group interview with the five pilot study subjects was conducted during week four for the following purposes:

1) To compare student concepts acquired through the written journals with direct observations.

2) To gather design criteria for the microworld.

3) To correlate pilot study findings with current research findings.

3.3.3 Group Interviewing Guidelines

Group interviews have the advantage of being inexpensive, data rich, flexible, stimulating to the respondents, recall aiding, cumulative, and elaborate (Denzin & Lincoln, 1994). This methodology is commonly used for exploratory or brainstorming purposes. The interviewer must be flexible, objective, empathic, persuasive, and a good listener. Merton, Fiske, and Kendall (1956) note the following skills required by the interviewer:

1) The interviewer must keep one person or a small coalition of persons from dominating the group.

2) The interviewer must encourage recalcitrant respondents to participate.

3) The interviewer must balance the directive interviewer role with the role of the moderator.

4) The interviewer should not allow the emerging group culture to interfere with individual expression.

Fine and Sandstrom (1988) provide the following additional guidelines for interviewing children:

1) The interviewer must become a friend to the subjects and interact in a trusted way.

2) The interviewer must not take an authoritative role.

3) The interviewer must not sanction the behavior of the participants unless they become disruptive to the process.

4) The interviewer must provide expressions of positive effect.

5) The interviewer must treat all subjects and ideas with respect.

6) The interviewer should allow equal time for all participants to express ideas.

7) Participants should not suffer harm or humiliation as a result of the interview.

In the pilot study, subjects were instructed that their ideas would be incorporated into a software application that will assist future students in learning the phases of the moon subject matter. The group interview was free form allowing for individual dynamics and characteristics. In order to avoid deterministic biases of the researcher, a structured series of questions were not used. The interview was moderated using the theme of "application development ideas for future learners."

The data gathered in the pilot study was transcribed, documented, and correlated with current research findings to serve as a base assessment for the development of revision 1.0 of the microworld.

Research Study Methods

Figure 3.3 outlines the research methods used in this study.

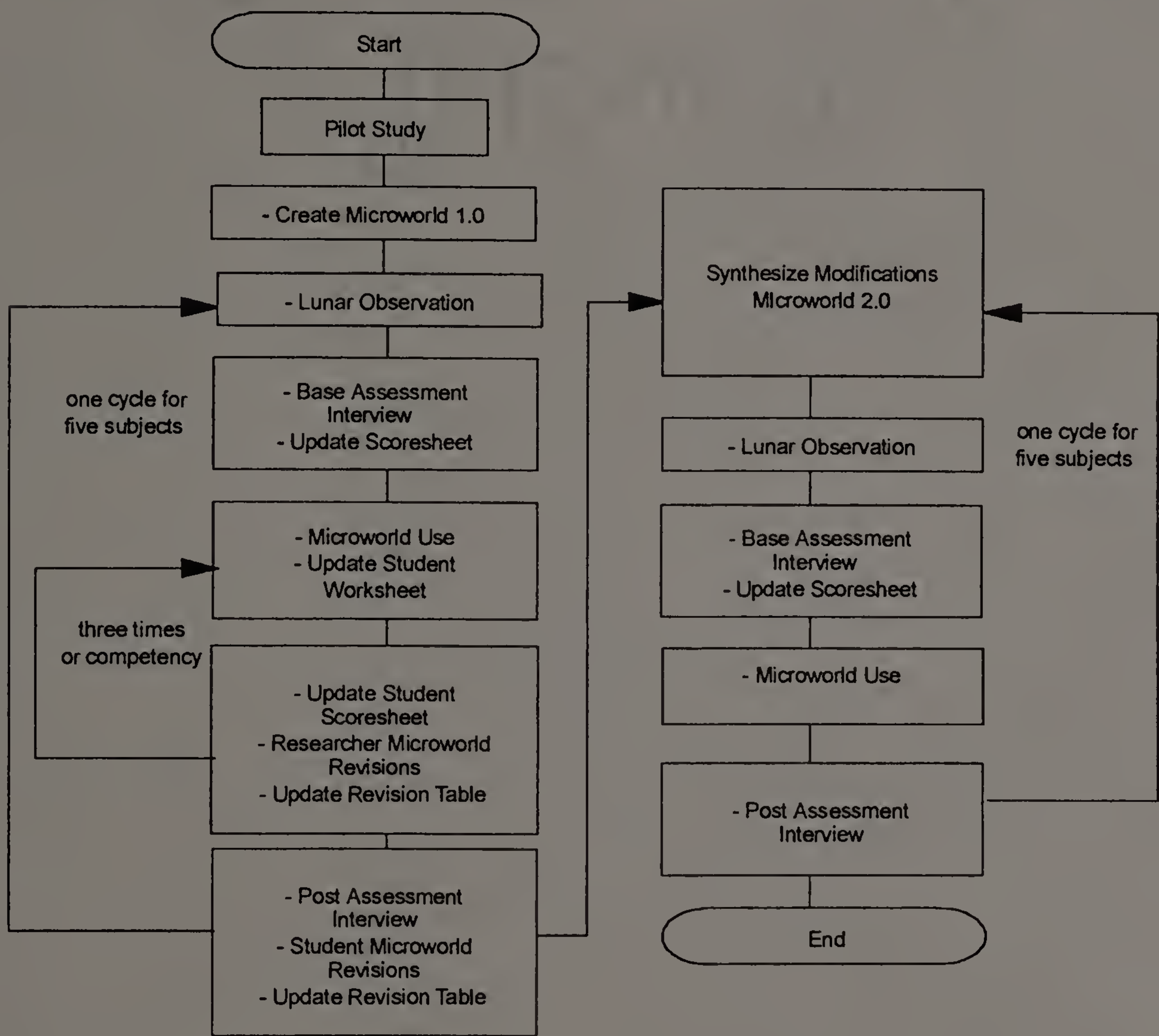


Figure 3.3: Research Methods

Similar to the pilot study, each student was instructed to observe and record lunar observations in a personal journal for two weeks. To avoid poor weather affecting the subjects' consistency in recording lunar behavior, the researcher provided a lunar calendar for the current and proceeding month. Students were told to use this chart only if lunar observations were unobtainable due to weather or family obligations. Following the two week observation period, the researcher posted a chart showing lunar observances for the following six weeks. Through clinical interviewing techniques, students were requested to explain the causes of the previously observed lunar phenomena recorded in their journals. A base domain assessment score was assigned and recorded for each student.

The students then interacted with Revision 1.0 of the microwrld. The microworld use was recorded using "screencam" technology. This technology records all voice, screen, keyboard, and mouse activity initiated by the student or researcher. The researcher was present during this session requesting that the student "think out loud" explaining thoughts and actions. The researcher also used clinical interviewing techniques to assist in accessing learner behavior. During and immediately following each session, the researcher requested feedback and potential application modifications providing information for comprehending phases of the moon. Once completed, the researcher transcribed the "screencam" into a worksheet that modeled the session. Then the researcher applied requested and personal modifications to the microworld based upon the students' current experiences. Student availability and complexity of requests required that all modifications were completed within a one week period. All modifications were recorded in a revisions table for each subject.

The cycle was repeated three times or until competency for each of the first five subjects. Competency refers to mastery of the knowledge domain of phases of the moon. For each iteration, an interview was conducted and a post domain assessment score assigned and recorded. Similar modifications requested by one subject were made available to other subjects immediately upon request through a revision library.

Following the completion of the iterations of the first five subjects, learner and researcher modifications were synthesized into Revision 2.0 of the microworld.

The remaining five subjects were instructed to observe and record lunar observations in a personal journal for two weeks. To avoid poor weather affecting the subjects' consistency in recording lunar behavior, the researcher provided a lunar calendar for the current and proceeding month. Students were told to use this chart only if lunar observations were unobtainable due to weather of family obligations. Following the two week observation period, the researcher posted a chart showing lunar observances for the following six weeks. Through clinical interviewing techniques, students were asked to explain the causes of the previously observed lunar phenomena recorded in their journals. A base domain assessment score was assigned and recorded for each student. Each students was allowed to interact with Revision 2.0 of the microworld for one hour. The researcher was present during this session requesting that the student "think out loud" explaining thoughts and actions. The researcher used clinical interviewing techniques to access learner behavior. Following the interactive session, an interview was conducted and a post domain assessment score assigned and recorded. Once completed, the researcher transcribed the "screencam" into a worksheet that modeled the session.

The journals and recorded (screencam) interviewing sessions served the following purposes for the research study:

1) To triangulate student concepts acquired through the recorded sessions and journals for validation of results. To minimize researcher bias in assessing conceptual gains, the researcher relied upon both the interpretation of the microworld sessions and corresponding journal entries of students.
2) To gather design criteria for the microworld.
3) To provide an additional learning environment for subjects.

4) To determine the knowledge acquisition level of the students throughout the six week procedure.

The individual assessments and recording of the subjects' use of the microworld required interaction with the researcher. The researcher provided information on the use of the microworld, however, questions that related directly to knowledge acquisition of the content domain were not to be answered directly. The subjects were required to answer questions posed by the researcher in a style referred to as clinical interviewing.

"Finding out" what a subject is thinking rests on an interpretation of a subject's response to a researcher's question. Johnson and Gott (1996) suggest a methodology with the notion of a "neutral ground" that requires interaction with subjects to be in their frame of reference and not the reference of the researcher. A core of three basic principles should establish a neutral ground: the task should be neutral, the interpretation should take place on neutral grounds, and the triangulation should be seen as a priority.

- A neutral task given to the child must be neutral in relation to the researcher's and subject's frames of reference.

- Interpretation must attempt to understand what a child is saying on his or her own terms and the researcher must guard against imposing meaning from his or her frame of reference.
- Triangulation requires that the researcher validate evidence from subject responses through several other parallel inquiries.

3.4 <u>Data Collection and Analysis</u>

3.4.1 <u>Domain Comprehension</u>

A student that exhibited the following qualities was designated as having a comprehensive understanding of lunar phases.

3.4.1.1 <u>Knowledge of Light</u>

A student must be aware that a shadow is the absence of light. A shadow must not be mistaken as a discrete object. A shadow may also exist even though the peripheral reflective light of an object is directly observable. Light travels infinitely in a straight direction. Light does not bend.

3.4.1.2 <u>Stock Identification</u>

A student must be able to identify necessary inventories. Identification of inventories was characterized by the learners ability to resolve the necessary systems required for lunar phenomena. Examples of inventories are the sun, moon, earth, and planetary orbits, although learners identified incorrect inventories such as clouds, trees, atmosphere, and other planets.

3.4.1.3 Lunar Perspective

A student must have the ability to describe a universal view of lunar phenomena. A universal view required multiple descriptions from perspectives of the earth, sun, and moon. The identification of visual perspectives were characterized as planar or three dimensional. A planar view was classified as any singular view identified by the learner without a global context or as any view that pertains only to the presented perspective absence of references to different perspectives. References that contain global contexts with multiple view perspectives were characterized as three dimensional.

3.4.1.4 Interdependence of Variables

The student must exhibit an inter-relational viewpoint that explains concepts involving indirect cause-effect relationships. Explanations of lunar phenomena that described relationships between the observational perspective, lunar orbit, and reflected sunlight would be an example of this. The interdependence of variables was categorized as phenomenological or inter-relational. A phenomenological viewpoint explained concepts using descriptions of formal structures focusing on direct cause-effect relationships. For example, an explanation that the shadow of the earth on the moon creates variational illumination would characterize this viewpoint. An inter-relational viewpoint explained concepts involving indirect cause-effect relationships. Explanations of lunar phenomena that described relationships between the observational perspective, lunar orbit, and sunlight would be an example of this. A student that could describe a lunar phase from any two perspectives would be another example of an inter-relational viewpoint.

3.4.2 Student Score Sheet

Table 3.1 is an example of a student score sheet for recording domain competency.

Table 3.1: Overall Student Scoresheet

Revision	**Light & Shadows**	**Inventories**	**Perspective**	**Variable Dependence**	**Score 0-4**
Scoring	1 point - Yes	1 point for - ALL	1 point - 3D	1 point - (In)	
Base	Yes No	Sun Moon Earth Orbits	Planer ✓ 3D	Direct Indirect	0
1.0	Yes No	Sun ✓ Moon ✓ Earth ✓ Orbits ✓	Planer ✓ 3D	Direct Indirect	1
2.0	Yes No	Sun ✓ Moon ✓ Earth ✓ Orbits ✓	Planer ✓ 3D	Direct Indirect	1
3.0	Yes ✓ No	Sun ✓ Moon ✓ Earth ✓ Orbits ✓	Planer ✓ 3D	Direct Indirect	2
Final Score					2

3.4.3 Session Modeling

Table 3.2 is a sample transcription of one iteration of a single session.

Table 3.2: Iteration Student Worksheet

Iteration Student Worksheet				
Student: S1		Iteration: 1	Revision: 1-1	
Transaction	Module Revision	Action	Assertions	Errors
S-C R-S S-R R-C	1-? 2-? 3-? ?-?	Statement (S) Action (A)	Lights & Shadows (L) Identify Inventories (I) Perspective (P) Variable Dependence (V) Other (O)	Misconception (MM) Application Confusion (AC) Phenomena Confusion (PC) Computer Feedback (CF) Researcher Feedback (RF)
S-C	1-1	A-Reads initial screen and clicks on the sun, moon, and then the earth.	O	
S-R	1-1	S-States that the sun does not rotate, but the earth & moon does.	I-Appears surprised that the sun stays still.	
R-S	1-1	S-Did you think the planets moved diffferently than what you are seeing?	O	
S-R	1-1	S-I knew the earth rotated around the sun, but never thought that the moon rotated around the earth at the same time.	I	MM
S-C	1-1	A-Rotates the moon about the earth with varying times. Tries six different time intervals and reverses the rotation. States that the sun side of the moon is always bright.	I	
R-S	1-1	S-Does this surprise you?	O	

The "transaction" column was denoted by an S-C (student-computer), R-S (researcher-student), S-R (student-researcher), or R-C (researcher-computer). The "module revision" column represented the module within the microworld and latest revision. For example, 2-3 would be a reference for the third revision of the second module. The "action" column designated an action or a statement accompanied by a description of the event. The "assertion" column identified the specific aspect of the knowledge domain and researcher comments. This column included more categories as additional insight was gained through the pilot study or research. The "error" column allowed the researcher to categorize misconceptions, application confusion, (usability), phenomena confusion, and feedback associated with each action.

3.4.4 Revision Table

Table 3.3 is a sample of the revision table. All revisions were mapped back to a student, session, statement, or action. The "student researcher" and "revision" column are self explanatory. The "intention" column was coded in a similar fashion to the "assertion" column of the session worksheet. An explanation of the intent of the change accompanied the categorization. A description of the change was documented in the "change" column.

Table 3.3: Module Revision

Table of Module Revisions			
Student Researcher	Revision	Intention	Change
S1	1-1	L-Exhibit that the moon and earth are always half illuminated.	Student was confused by a moon being half white and half black. This was meant to show the presence of reflected light and the absence of reflected light. A pop-up spyglass was inserted to assist in this confusion.
S1	2-1	...	
R	3-1	...	
S1	2-2	...	

3.5 Data Reduction

The microworld sessions were transcribed and recorded using the worksheets previously described. The sessions documented in the next chapter were highlights of the transcriptions and do not include information or conversations that were not relevant to the study. The sessions do not document the researcher's methods requiring the students to "think out loud".

The worksheets were further reduced to session flowcharts based upon the observed data. The worksheet sessions characterize a finer granularity of the interactions of the researcher, student, and microworld. The session flowcharts attempt to characterize gross level patterns recognized by the researcher while transcribing the data. The following terminology and characterizations were used to generate session flowcharts.

Play Play was characterized by a free form usage of the microworld. It involved interaction without direction. Students would describe play interaction out loud as "playing", "just because", "I just am, or I do not know."

Cognitive Conflict Cognitive conflict was characterized as observed confusion or disequalibrium. Observed behavior was different from expected behavior. Students would typically describe cognitive conflict out loud as "huh?", "that is not what I expected", or "wait". Cognitive conflict was also displayed by students in several ways. One was by staring at the researcher with a quizzical look. Another was displayed when the student simply stopped interacting and stared at the computer screen. In most cases, cognitive conflict was validated with a pointed question by the researcher like "Are you confused?" or "Did this surprise you? "

<u>Conjecture</u> The conjecture characterization was used as a compromise between a hypothesis and a guess. Students would not necessarily formulate a formal hypothesis. In many cases the student would make a tentative statement, ask questions, or make a guess that resembled a hypothesis. The following statements all refer to potential conjectures.

- "Light does not bend."
- "Does light bend?"
- "I think that light can bend."
- "Light reflects but does not bend."

A conjecture would only be characterized if it were followed by an investigation to support or deny it.

<u>Investigation</u> An investigation must follow a conjecture with the intent to support or deny the initial theory. If the investigation was not in direct response to a conjecture, it would potentially be considered play. Students in an investigative mode would describe out loud observed phenomena such as "in this example, light cannot bend" or "you see that both the Earth and Moon are only bright on one side."

<u>Inference</u> An inference was denoted as an tentative or absolute conclusion following an investigation. The following are examples of absolute inferences.

- "Light bends for sure."
- "No, light does not bend."
- "Light bends, but not nearly as much as I originally thought."

The following are examples of tentative inferences.

- "I believe that light bends, but I'm still not sure."
- "The earth does not cast a shadow on the Moon, but I'm still not sure why."

Analogies Analogies were characterized as attempts to assimilate observed behavior. An example of an analogy would be a student comparing the observance of the Moon from Mars to approaching a campfire at night.

Incidental Learning Incidental learning included conversations and discussions outside the scope of the intended investigation or microworld.

3.6 Analysis of Data

The defined procedures and protocols allowed the researcher both quantitative and qualitative analysis. The iteration score sheets provided objective measures for individual and group conceptual gains. The session worksheets and revision tables provided a mechanism to gain an insight in to students conceptions of self-learning and the ability to link measurable conceptual changes (individually and holistically) to specific implementations (revisions) of the microworld. The session worksheets allowed the researcher to create models of self-learning and link those models to specific content domains and microworld implementations. Figure 3.4 represents the initial model for describing cognition and conceptual change in learners for this research. The objects that convey the microworld and conceptual change were expanded to infer the effects of the iterative implementations and will be discussed in chapters 4 and 5.

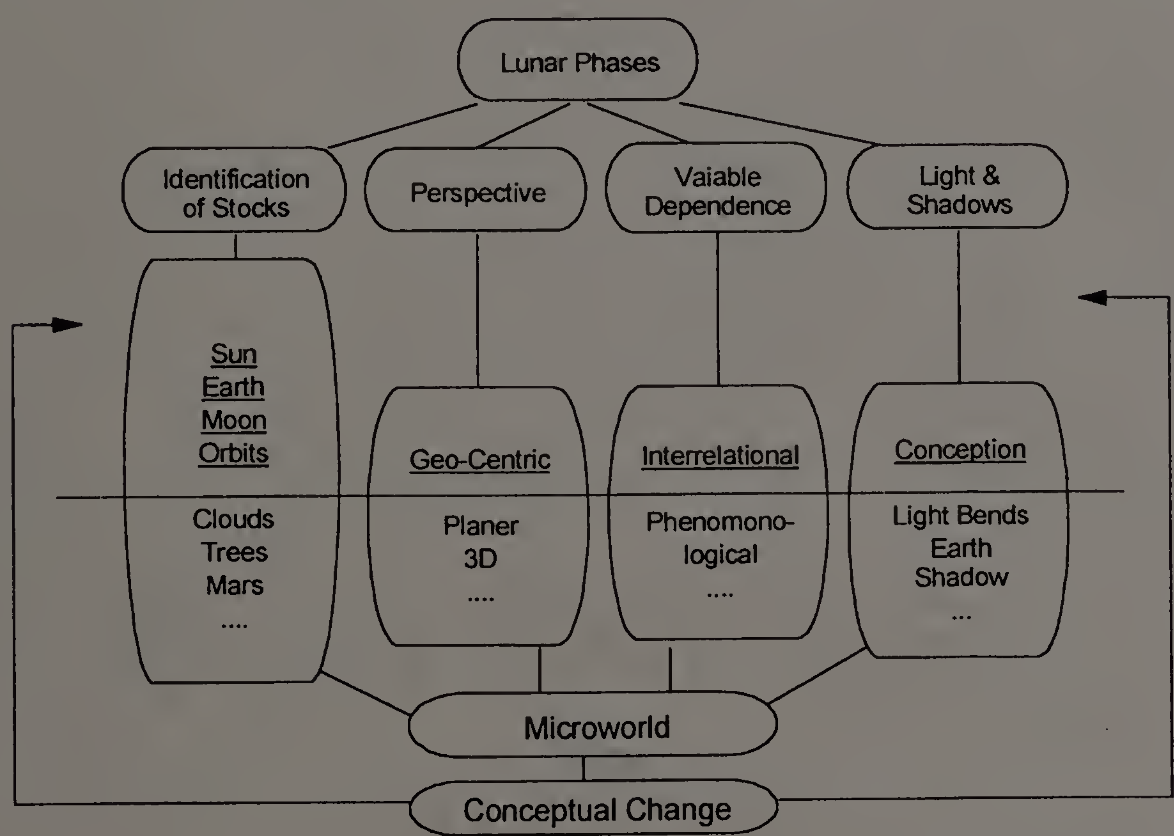


Figure 3.4: Domain Model

3.7 Validity Measures

An amongst groups descriptive validity measure was conducted to triangulate results obtained through journals and microworld activities. All subjects were required to maintain a journal with entries that corresponded to microworld sessions. In an attempt to avoid potential researcher bias, conclusions were based upon both data sources. There were no reliability tests conducted in this study.

CHAPTER 4

MICROWORLD DEVELOPMENT

4.1 Overview

The pilot study was useful in providing both methodology experience and data for refining the main study of this research.

Final results of the pilot study were utilized to develop revision 1.0 of the microworld.

4.2 Pilot Study

4.2.1 Journal Entries

Students successfully observed the moon over a two week period. The workbook provided for seven observation entries per page. Students were asked to be scientific in their observations and to record landmarks (trees, houses, mountains) that enabled them to track the moon. Learners were not able to accurately draw the landscape detail to their satisfaction within the space provided. The main study research journal illustration space was doubled in size to accommodate detailed descriptions.

4.2.2 Journal Theories

The pilot journal instructed students to formulate their ideas about the potential causes of the events that they observed. Three of the five students did not complete this effort independently. These students confused the formulation of ideas (hypotheses) with providing the correct answer. Journal entries for these students simply read "I do not know" or were left blank. The researcher struggled with the first of these three students and attempted to discuss analogies of similar phenomena. The student would answer with phenomenological statements like "it just looks different" or "it is different because it changes shapes." The student would not consider speculating about potential causes. She was very reluctant to be speculative as opposed to simply providing an answer. This pattern would become an underlying theme of all learners in this study. So that incorrect speculation would not be a negative experience for the student, the researcher suggested that she should assume the position of the first scientist in an early civilization where no one knew what caused the moon to appear differently each night. The queen of this civilization has asked her to provide potential reasons for the observed phenomena. Soon after this play acting, the student hesitantly offered an obstructionist theory to account for the observations. When asked why she didn't offer this theory initially, she answered "I didn't realize you were interested in wrong ideas." When asked "How do you know it is wrong?", the student responded with "because I do not know the right answer." The play acting experience was incorporated in the main study to assist students in formulating initial theories in a comfortable manner.

4.2.3 <u>Clinical Interviewing</u>

The pilot study was invaluable for the researcher in gaining clinical interviewing experience. Quite often during the early interviews, students would answer with statements like "it just is", "because", and "I'm not thinking anything." To be able to involve the student with the activity while not leading the student in a researcher directed path requires practice. The researcher learned to offer multiple suggestions without giving any greater merit than the others. The researcher found that using the words "that's right" or "correct" influenced the students too heavily. Comments by the researcher soon gave way to statements like "that is interesting", "can you explain" … and "I have never thought of that, could you help me more understand what you are thinking." The research by Johnson and Gott (1996) that suggests a methodology with the notion of a "neutral ground" requiring interaction with subjects to be in their frame of reference and not the reference of the researcher formed the foundation of the clinical interviewing techniques used in this study.

4.3 Theory Analysis

Initial concepts formulated by the students in the pilot study evolved around three different theories involving obstructions, eclipses, and light refraction.

4.3.1 Obstruction Theory

The obstruction theory is illustrated in Figure 4.1.

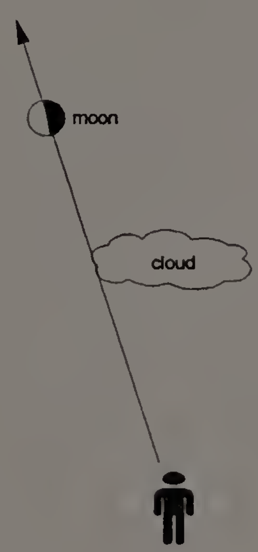


Figure 4.1: Obstruction Theory

The obstruction theory professes that clouds, trees, or other natural phenomena block a portion of the moon from view. If no obstructions are present, a full moon will be visible. Gibbous and crescent moons are a result of partial obstructions. One student in the pilot group asserted this theory. This student was asked if he observed a gibbous moon on a clear night without any clouds. The student admitted that he had observed a gibbous moon on what appeared to be a clear night, but rationalized that the clouds were so high in the atmosphere that they could not be seen with the naked eye. The student sensed that if she owned a telescope, she would be able to see the clouds. The researcher reviewed the cyclic nature of the phases of the moon with the student and gained consensus of this pattern. The student and researcher also agreed that weather was unpredictable. Given these agreed upon observations, the student was asked how an unpredictable weather event could cause a predictable cycle of the moon. Without hesitation, the student stated that the jet stream was very predictable, for example, traveling West to East, and that event could result in a pattern of cloud obstructions.

4.3.2 Eclipse Theory

Figure 4.2 is an illustration of the eclipse theory.

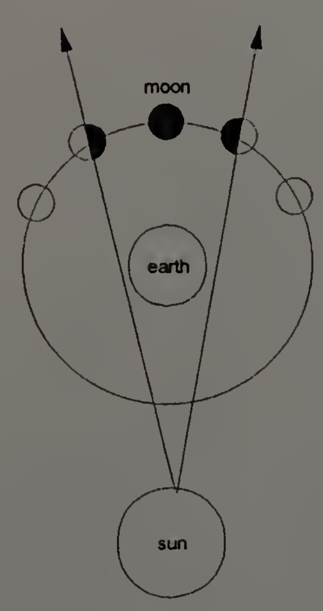


Figure 4.2: Eclipse Theory

Learners adhering to the eclipse theory believe that the earth is casting a shadow on the moon. Three of the five pilot study students initially held this theory. Approximately half way through the lunar cycle, the moon passes behind the earth blocking the sunlight. Crescent and gibbous phases result when the moon enters and leaves the earth's shadow. The researcher reviewed the cyclic nature of the phases of the moon with all of the students and gained consensus of this pattern. Using the drawings provided by the students in support of their hypotheses, the researcher showed the students that the majority of the time the moon would be full. This was not the case with the students' observations and lunar calendars. When asked to explain the difference between their theories and observations, two students immediately stated that light bends. Space or atmosphere of the earth causes the light to bend and elongates the time that the moon is in the shadow of the earth. Secondary illustrations, similar to the ones shown for the refraction theory (explained later in this chapter), were drawn. Neither student could fully correlate the lunar phases with their explanations but felt that they were "on the right track."

The third student accommodated for difference between observations and theories less quickly. After some thought, the student felt that the earth actually reflected light and that the position of reflected light caused the phases. The moon passing behind the earth would result in a new moon, and the moon passing in front of the earth would receive full light reflection from the earth. The crescent and gibbous phases were partial reflections of the light from the earth throughout the lunar cycle. Figure 4.3 illustrates this theoretical advancement.

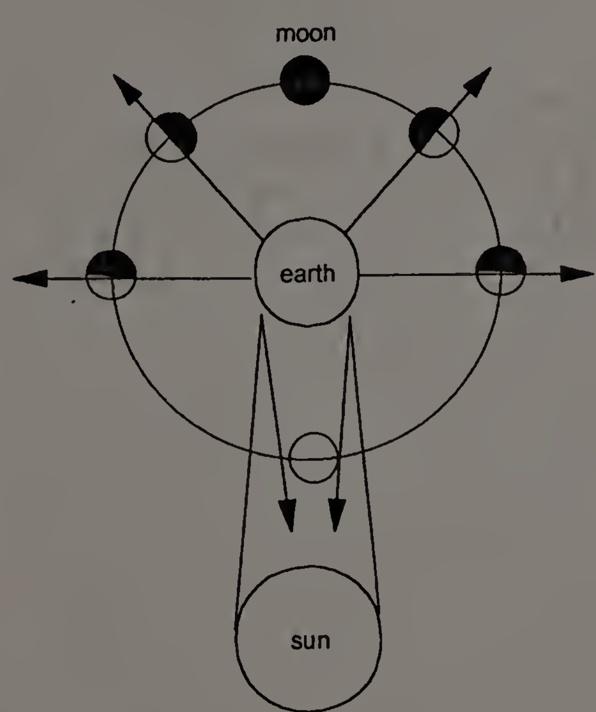


Figure 4.3: Reflection Theory

The student was questioned as to how the sunlight was reflected off of the far side of the earth. The student believed that light was "held" in the atmosphere and that it actually might bend a little.

4.3.3 Refraction Theory

One student developed the refraction theory illustrated in Figure 4.4. The principle of this theory is similar to the advanced theories of the students that began the study with the eclipse explanation for lunar phases. The student explained that light would bend through the atmosphere causing observations similar to the lunar calendar. This was not the student's first theory. Prior to observing the lunar calendar, the student felt that the phases were caused by the earth's shadow, but after viewing the calendar, concluded that his initial theory did not account for the length of the different phases. Light must bend to cause phases of the moon.

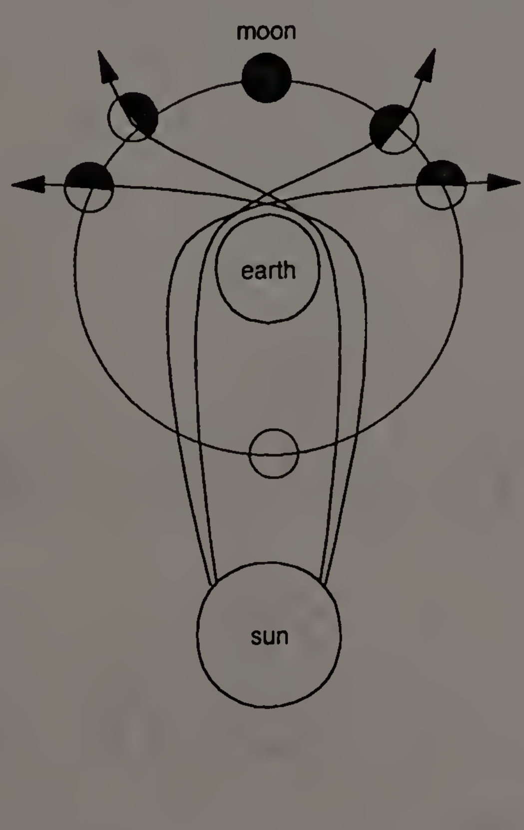


Figure 4.4: Refraction Theory

4.3.4 Theory Explanation

One student began the study with the obstruction theory and did not attempt to accommodate for observed contradictions. The theory was supported by weather phenomena beyond observable behavior. Four students began with the eclipse theory, of which three advanced to a variant assertion involving the bending of light. The remaining student, forced to accommodate for the observed lunar behavior, advanced a reflection theory, but maintained that an eclipse effect was still relevant.

In one sense, the researcher believes the obstruction theory can be viewed as a primitive variant of the eclipse theory. An object is obstructing the view of the moon. In another sense, the obstruction theory can be considered advanced to the eclipse theory, as it is the only theory that places the perspective from earth observing into space. The eclipse theory, refraction theory, and reflection theory are all from an outer space perspective. The refraction theory is an obvious advancement of the eclipse theory allowing students to hold on to initial beliefs. The reflection theory may be considered the most advanced. The reciprocal of the reflection theory, that is, that the reflected light from the moon as seen by an observer from the earth, is the true cause of lunar phases.

Based upon pilot study data, the researcher suggests the conclusions from the following observed behaviors. Students are more apt to hold on to initial beliefs and explain scientific observations through phenomenological reasoning (Anderson and Smith, 1986). Students believe that light bends (Shapiro, 1994). Students perceive lunar phenomena from an outer space perspective or a "God's eye" view (Schneps, 1989; Marschall, 1996), and students believe that the moon orbits on the same plane as the sun and earth (Foster, 1996; Marschall, 1996).

4.4 Constructivist Teaching Activity

A "hands on" exercise, "Look to the Moon," described by Foster (1996) was utilized by the researcher. Subjects mounted a small Styrofoam ball on the end of a meter stick. Standing in a darkened room, students held the meter stick near their nose and pointed it toward the ceiling at a 45 degree angle. The researcher held a table lamp with the shade removed in the middle of the room representing the sun. The subjects would turn themselves in a circular motion, providing a line of sight similar to actual moon observations from the earth. Students were told that their head was the earth, the lamp was the sun, and their Styrofoam ball was the moon. Students were also asked if they could support their final theories using these tools.

Students rotated the "moon" about their heads and quickly observed that differing shapes appeared. Many were able to cause an eclipse effect by holding the stick down and away from the lamp behind their torso. The "moon" would be half illuminated by the light source while the torso cast a shadow on the opposite half. After great discussion, it was determined that this would cause two new moons and not support the observed behavior. One student finally rotated the "moon" on a plane parallel and above his head observing a complete lunar cycle. All students were able to replicate the procedure and produce similar phenomena. One student, however, noticed that she observed a half moon when a student standing near her was explaining observations to another student as a new moon was beginning to appear from his perspective. A major disagreement occurred when everyone observed different behaviors. The students were not able to reconcile these differences themselves. The researcher asked the students to walk around the "moon" two-by-two explaining their observations. There was significant controversy when their bodies cast a shadow on the moon. Two students quickly concluded that their initial observations were correct. The researcher raised the "moon" and "sun" to correct for this error. All agreed and concluded that walking around the moon produced the same results as revolving the moon around their heads.

Not all students were clear that the moon orbited the earth and that the earth orbited the sun. There was general agreement that the moon orbited the earth; however, significant discussion and disagreement occurred concerning the orbits of the earth and sun. Multiple scenarios were investigated and there was no generally agreed upon conclusion. The group could not contain the breadth of the discussion to a single theme.

A variation of the above activity was also used. Learners placed different shaped objects (spheres, cones, cylinders, and cubes) in the center of a darkened room with an external light source allowing the students to see multiple objects from different perspectives by moving about the room. Students were placed at different stations and asked to explain their observations to the rest of the group. The group generally agreed upon observations, exchanged stations, and were confident in their statements. Students were generally surprised when the cube did not exhibit the same effects as the cone and cylinder. The cone and cylinder gradually reflected light in a linear fashion when the light source or object was rotated. The cube would suddenly illuminate an entire flat surface. The students were also generally interested when the tops of the cylinder and cube were not illuminated, although they could see that surface better than the non-illuminated surface. The researcher lowered the light source until the top surface was as dark as the opposing surfaces.

Students discussed the amount of light "hitting" the surfaces, the similarities observed in the previous exercise, and the causes of darkness. The illumination of the surfaces of the cube and the similarities to the illumination of the top surfaces of the cube and cylinder when the light source was lowered were the main themes of the discussion. Reflected light was never a part of the discussion, however, more light hitting a surface caused a brighter object. The students were asked if light could bend. All generally agreed that light could bend. The students were then asked to create an experiment with their tools that would show that light bends. Students repeated previous experiments and used the sticks with the Styrofoam balls to "mark the path of the light". One student suggested that they use a string to mark the path of the light from the lamp to the object. A shoelace was substituted. The student placed the cube on an angle toward the light source. While one student held the slanted cube and two students held the string at either end, the string was held up in the middle "showing" that light could bend. The researcher showed that a straight path could also be substituted for many different places on the illuminated surfaces. Students agreed with this observation, but generally still felt that light could bend, but not as much as they originally thought. Their theory was strengthened when one student proclaimed that his barn blocked all the light on his basketball court late in the evening, but he could still see it. All gave similar experiences. The students had not yet grasped scientific concepts such as light reflection, absorption, and refraction.

4.5 Group Discussion

One 90-minute group interview was conducted to assist with the development of revision 1.0 of the microworld. All students were familiar with the use of various computer applications. Subjects were instructed that their ideas would be incorporated into a software application would will assist future students in learning the subject matter. The group interview was free form, allowing for individual dynamics and characteristics. There were no structured series of questions to avoid deterministic biases of the researcher. The interview was moderated using the theme of "application development ideas for future learners." Students were asked to discuss strategic moments in the hands-on exercise or student-researcher discussions that changed the way they thought about lunar phases.

Many of the ideas presented by the students were a recapitulation of the pilot study exercises. One example was to create a dark room and allow users to shine a flashlight on different shapes from different angles. Another example consisted of creating our galaxy and rotating it around a person in a dark room. To stimulate further discussion, the researcher demonstrated a prototype illustrated in Figure 4.5.

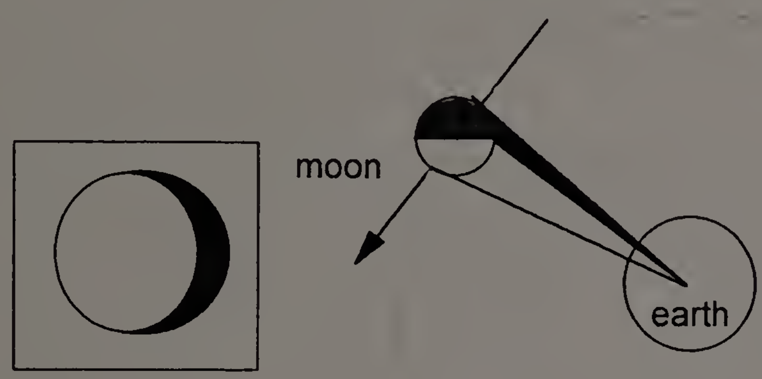


Figure 4.5: Prototype Application

The prototype allowed the moon to orbit the earth from an outer space view (X,Z) above the North Pole. A second view (X,Y), as seen by somebody standing at the North Pole, was synchronized with the orbit of the moon. The application was created using two dimensional line art.

The prototype microworld stimulated significant discussion. Following is an abridgment of the discussion.

1. Students felt that the prototype microworld should be realistic and allow viewing of objects from anywhere in a room or space. A few students mentioned space travel via a rocket ship.

2. The prototype microworld looked like a cartoon and was difficult to relate to real life situations.

3. The prototype microworld was boring because it would only allow users to watch the moon orbit the earth. Students felt that they should have a great deal of control over the movement.

4. The application should allow users to explore objects in detail and possibly create new objects.

5. There should be an exam following the microworld to see how well the students learned the lesson.

4.6 Pilot Study Summary

The pilot study was useful in providing both methodology experience and data for refining the main study of this research. The theories developed by the students are consistent with current research findings (Bisard, Aron, Francek, and Nelson, 1994; Schneps, 1989). The hands-on activities were beneficial in contradicting existing theories and providing a medium for cognitive change. Students provided useful design criteria and expectations for the development of a computerized microworld.

4.7 Microworld Development Revision 1.0

The development of the initial microworld was based on student input, an extensive review of microworlds and conceptual change, and techniques used to address learner misconceptions. The latter two elements were extensively discussed in the review of literature.

Perkins and Unger (1994) attributed the conceptual change of learners' representations to three principles. First, a microworld reduces the cognitive load by minimizing variables and quickly duplicating similar experiments. These representations allow more freedom to inquire in a less cumbersome problem space. Reducing the number of variables allows a learner to clarify cause-effect relationships without attention to extraneous information. Secondly, a microworld reveals immediate implications to learner hypotheses. Students can quickly examine similar mental constructions over different scenarios in a short amount of time. Thirdly, a microworld provides effective imagistic analogies.

Brown and Clement (1989) offer the following four steps in overcoming learner misconceptions:

1. A usable anchoring system conception must be present.

2. An analogical connection between an anchoring example and target situation should be developed explicitly through the use of intermediate analogies.

3. Engage the learner in a process of interactive teaching and analogical reasoning.

4. Require the learner to construct a new explanatory model of the target situation.

The initial revision of the microworld consisted of a shape exploration module, an outer space exploration module, and a phases of the moon module. The microworld was assembled using ToolBook Instructor 5.0 and Calagari TrueSpace 3.0.

4.7.1 Shape Exploration Module

The shape exploration module was an anchoring system and intermediate analogy intended to address the concepts of reflected light and viewing perspective using real world experiences. It also revealed immediate implications to learner hypotheses through experimental interaction. Figure 4.6 is an illustration of the shapes exploration module.

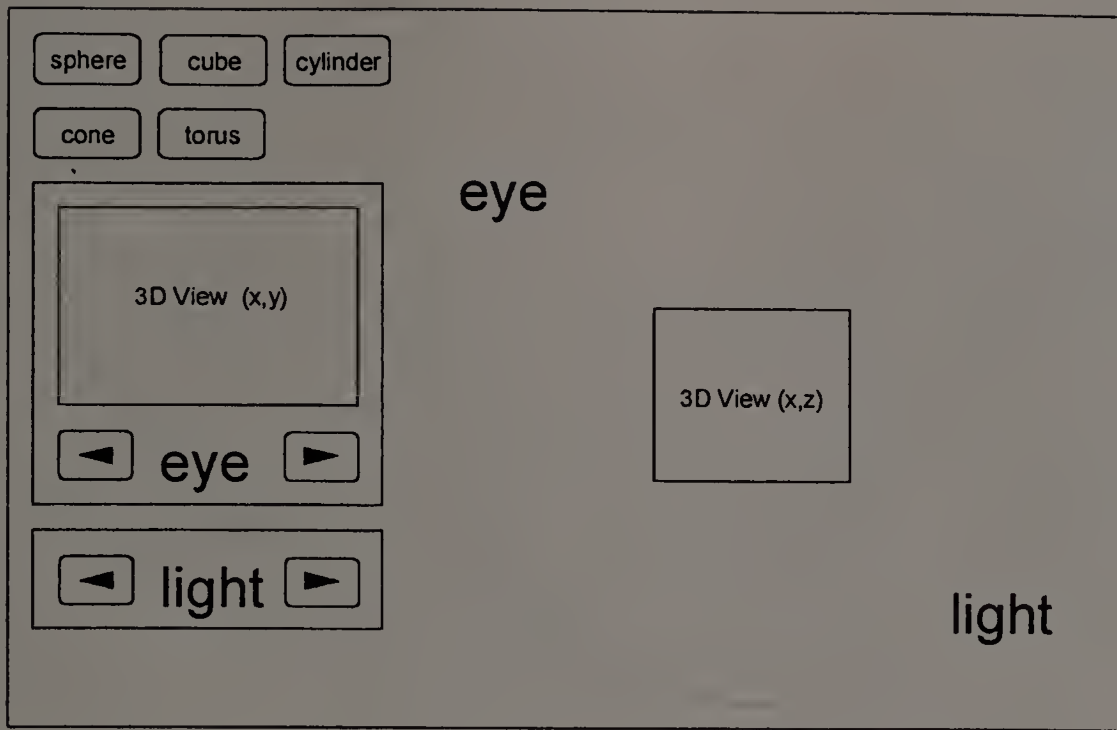


Figure 4.6: Shape Exploration Module

The shape exploration module consisted of dark space that allowed students to pick and illuminate a shape from any angle by moving a light source in a circular fashion. The 3D view (X,Z) to the right exhibited a view of the shape as if the viewer were standing above. The 3D view to the left exhibited a view of the shape as if one were standing on the side. The interface allowed a student to pick any of the shapes and move the eye or light about the shape. The "eye" is a place holder for an infinite number of perspectives that can be chosen by the user. All 3D views were synchronized providing correct illumination and shading aspects. This interactive environment allowed students to engage the learner in a process of interactive teaching and analogical reasoning.

Calagari Truespace 3.0, a three dimensional solids modeling computer application, was used to develop the virtual world of the shapes, light sources, and view perspectives. Figure 4.7 is an illustration of the virtual model used to develop the scene sequences.

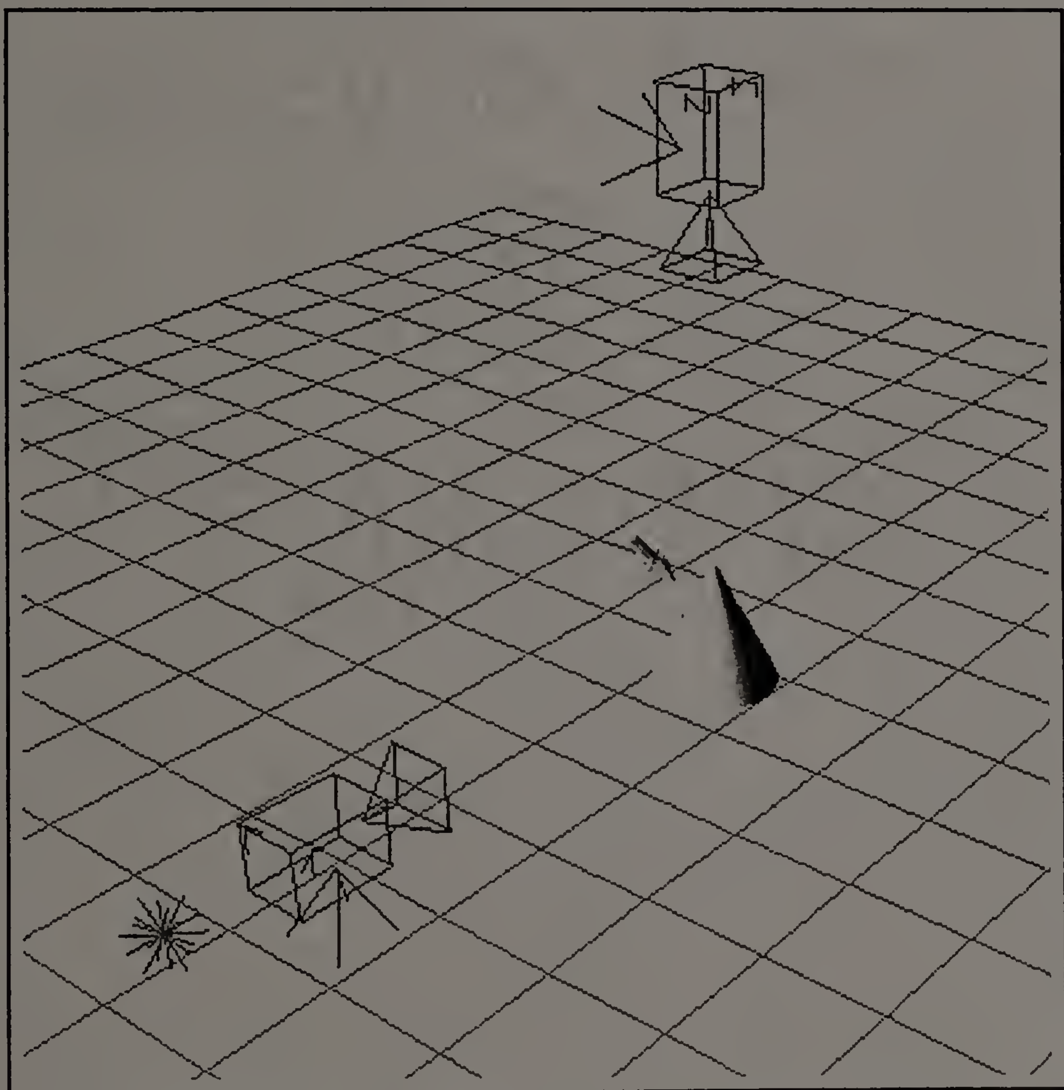


Figure 4.7: Calagari Shapes 3D Model

A camera was placed above and beside the shape to film the X-Z and X-Y planes respectively. The light source (located behind the camera in the lower left) was rotated 360 degrees about the shape. Two film frames were generated for each plane and degree location of the light source. The procedure was repeated for all five shapes (cube, sphere, cylinder, torus, cone) by simply replacing the object and refilming the light rotation. The correct viewing perspectives were displayed by ToolBook scripts each time the eye or light source was moved. See Appendix C for a complete listing of the ToolBook scripting language used in this study.

4.7.2 <u>Outer Space Exploration Module</u>

The outer space exploration module was a continuation of stepped analogies intended to address the concepts of reflected light and viewing perspective using multiple outer space view experiences. Similar to the shape exploration module, it was intended to reveal immediate implications to learner hypothesis through continued interaction of multiple outer space perspectives. Figure 4.8 is an illustration of this module.

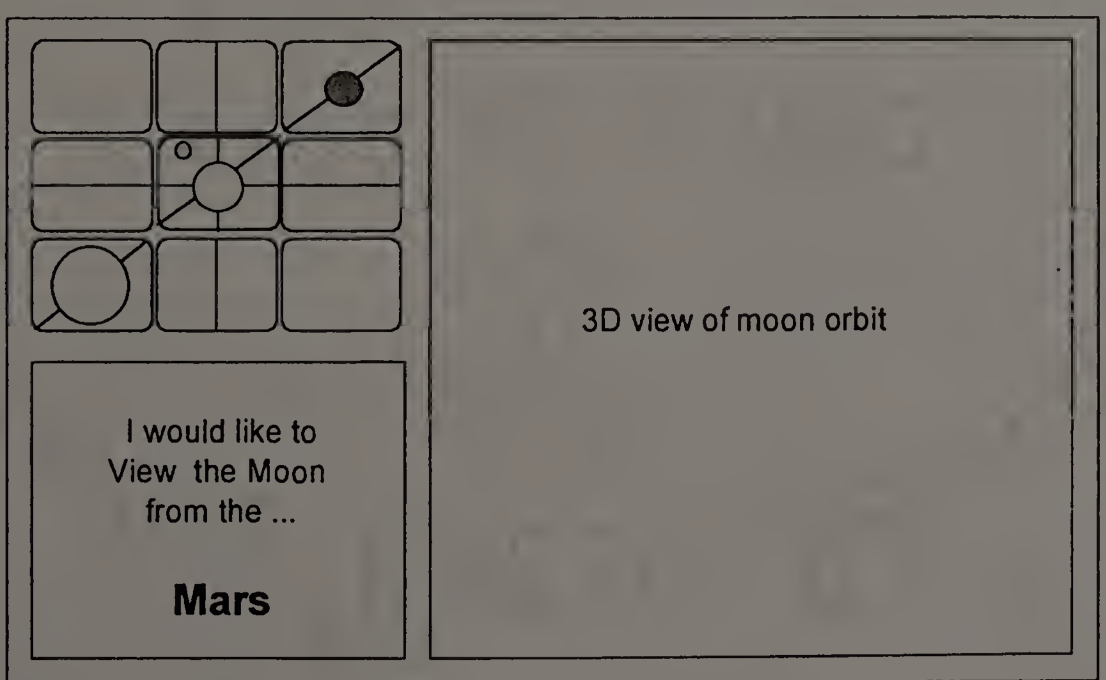


Figure 4.8: Outer Space Exploration Module

A control panel located in the upper left allowed the student to view the moon rotating about the earth from the following perspectives.

1. Sun
2. Mars
3. Earth
4. Above the Earth
5. Beneath the Earth
6. From each side of the Earth (relative to the Sun)
7. Beneath and to the lower left of the Earth (relative to the Sun)
8. Above and to the upper right of the Earth (relative to the Sun)

A description of the view would appear beneath the navigator and one revolution of the moon about the earth would be displayed in the stage to the right.

Calagari Truespace 3.0 was used to develop the virtual world of the planets. Cameras were placed strategically to capture the moon's orbits from each the eight previously described locations. Figures 4.9 and 4.10 represent still images of the moon from the right and from Mars respectively. A white background has been substituted in the following figures for display purposes.

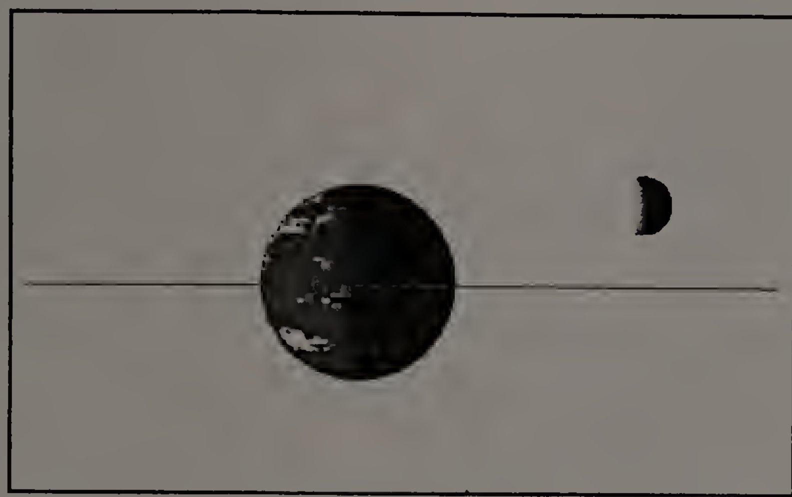


Figure 4.9: Side View Of The Earth And Moon

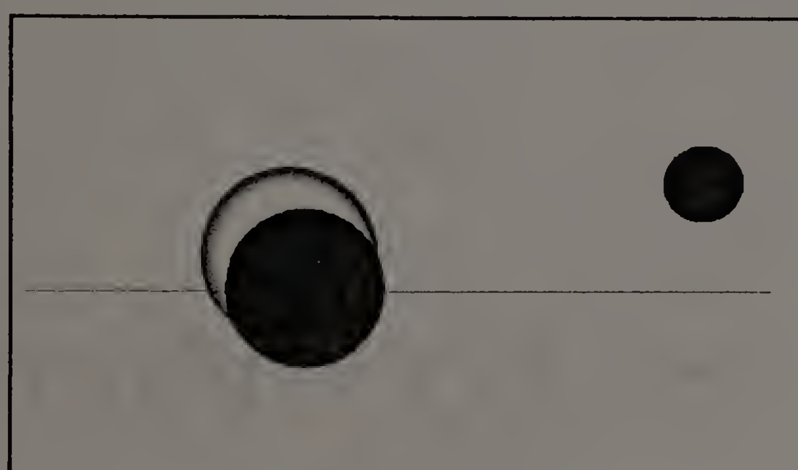


Figure 4.10: View Of The Moon From Mars

The camera was stationary for all views with the exception of the view from Earth. A still camera placed at a significant distance could capture the entire revolution of the moon about the earth within a single view. A static camera placed upon the earth would capture a small portion of the moon's orbit within a single view. The camera placed upon the earth was programmed to track the moon through the entire cycle. This produced a film sequence displaying all lunar phases with both the Sun and Mars appearing temporarily.

4.7.3 Moon Phases Exploration Module

The moon phases exploration module was a combination of the previous modules applied to lunar cycles. It also revealed immediate implications for learner hypotheses through experimental interaction with lunar phases. Figure 4.11 is an illustration of the moon phases exploration module.

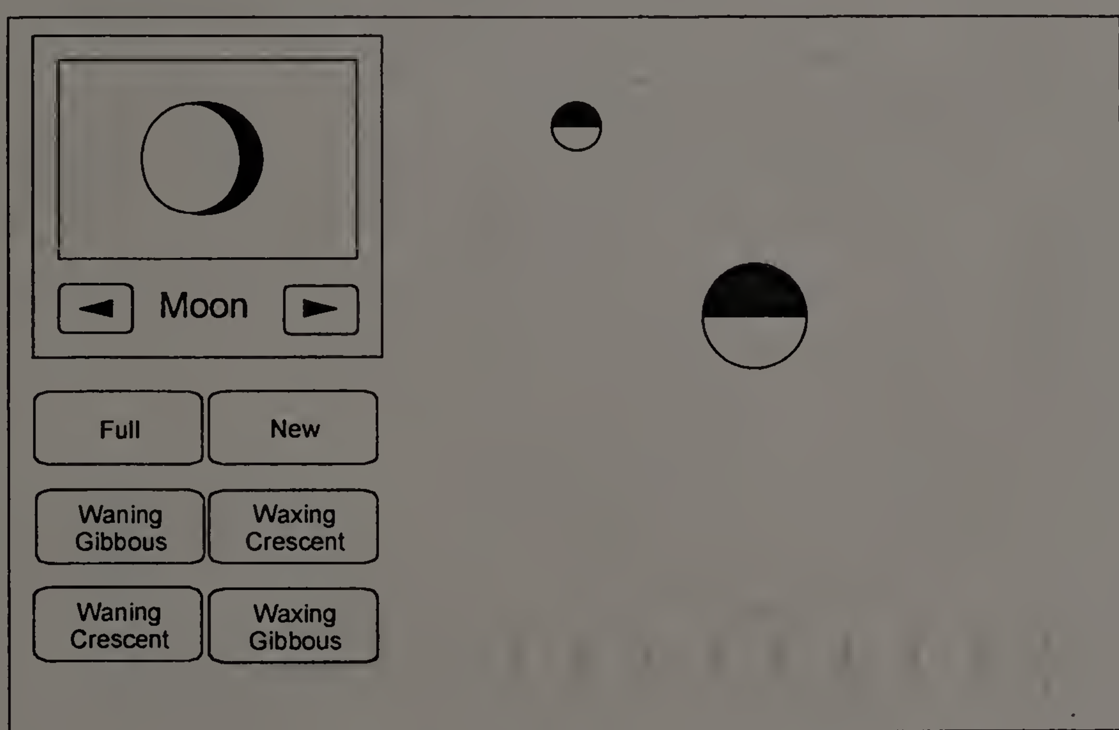


Figure 4.11: Moon Phases Exploration Module

Students could move the moon clockwise or counterclockwise about the earth as viewed from above in the X-Z plane. A view of the moon as seen from earth (X-Y plane) would be displayed in the stage located in the upper left corner. A description of the behavior of the moon would be highlighted by one of six buttons located in the lower left corner. Following is a list of the behaviors.

1. New Moon
2. Waxing Crescent Moon
3. Waxing Gibbous Moon
4. Full Moon
5. Waning Gibbous Moon
6. Waning Crescent Moon

A student could alternatively press any of the moon button descriptions and a synchronized video sequence (both planer views) would be displayed for the associated phase.

Calagari Truespace 3.0 was used to develop the virtual world of the lunar cycle. This required two cameras to film synchronized video clips. A static camera was located above the Earth filming the entire depth of field. An additional camera was programmed to pan the moon throughout the lunar cycle. Two film sequences, one for each camera, were captured for each degree revolution of the moon about the earth. The Toolbook scripting language was used to coordinate film sequences within this module. Figure 4.12 illustrates the virtual 3D model used within this module.

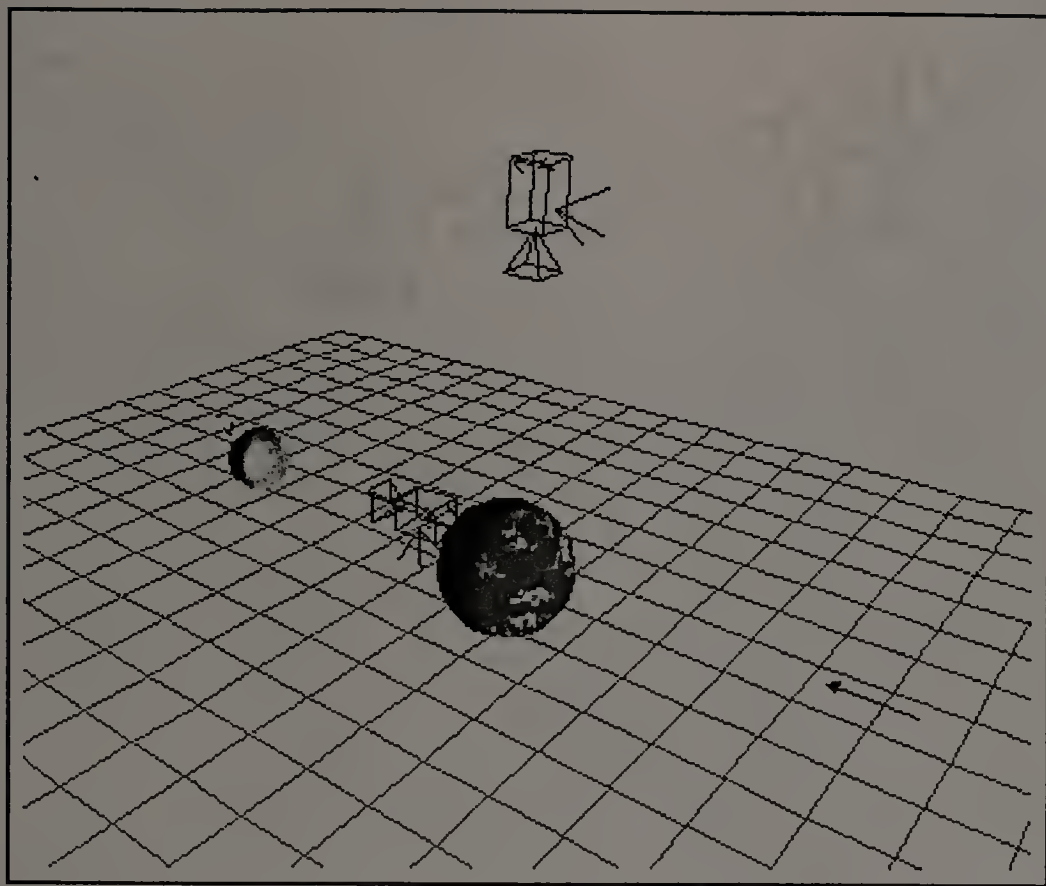


Figure 4.12: Caligari Phases Virtual Model

4.8 Microworld Development Summary

The development of the initial microworld was based on student input, an extensive review of microworlds and conceptual change, and techniques to address learner misconceptions. Using Caligari 3.0 to model virtual worlds, video sequences were generated for incorporation into a multimedia development environment, ToolBook 5.0. Three interactive modules were created using a scripting language that allowed students to explore shapes, reflected light, planetary orbits, and lunar phenomena. The shapes module enabled students to investigate properties of reflected light on different solid forms. The outer space exploration module enabled students to explore lunar phases from multiple perspectives. The phases module enabled students to investigate any part of a lunar phases from a single perspective.

CHAPTER 5

RESULTS

5.1 Overview

This chapter consists of a brief description of the microworld sessions, journal entries, student design requests, session flowcharts, and domain score sheets for each of five sessions.

5.2 Microworld Analysis and Design Sessions

5.2.1 Student Subject - Cal

Base Journal Entry

Following a two week observation of the moon, Cal documented the eclipse theory described in Chapter 4 and illustrated in Figure 4.2.

Microworld Revision 1.0

Session Description

Cal was the first of the five students that participated in this phase of the study. In was evident in the first session with Cal that he was obsessively concerned with providing the correct answer. Cal wanted immediate correct or incorrect feedback from the researcher based upon his interaction with the microworld. Considerable time was spent with Cal to make him feel comfortable with a "free-form" investigative environment."

Cal investigated the shapes module playing with different shapes, views, and lighting angles. Cal was surprised that he could not see the top of the cylinder in the overhead view. The sphere, torus, and cone could be seen in both the overhead (X,Z) and transverse (X,Y) views. The cube and cylinder could only be seen in the transverse (X,Y) view. The 3D models provided true lighting effects and would not illuminate flat surfaces within the same planes as the light. See Figure 4.6 in Chapter 4 to clarify the perspectives. The researcher asked Cal if there were any other shapes that he thought he may not be able to see the top. Cal tentatively responded that the cube my exhibit this behavior and asked if his answer was correct. The researcher encouraged Cal to pick the object and to see for himself. Cal picked the object and was pleased to see that he could not see the top of the cube. A review of the shapes was conducted by Cal with positive reinforcement of the expected results. Cal concluded the phases session by stating that "light can't bend that far over on flat surfaces, but light can bend on curved surfaces."

The views module was the next to be investigated (Chapter 4, Figure 4.8). This module allowed students to view the Moon orbiting the Earth from multiple outer space perspectives. Cal investigated many views and then reported "half of the moon is always bright." More views were tried and Cal then paused for a longer period of time when viewing the moon from Mars (the Moon and Earth appeared in total darkness). Cal stated that he was confused and tried more views. "The side closest to the Sun is always bright," was his next conclusion. Switching to the view from Mars, Cal stated very confidently that Moon was still "half bright" but you could not see it from Mars.

Cal next investigated the phases module (Chapter 4, Figure 4.11). After moving the Moon about the Earth a few times, Cal was confident that he could tell the researcher the correct phase of the Moon by looking at the position of the Moon about the Earth. Cal was again interested in providing the correct answer. He made no attempt to relate his experienced observances within the previous modules to the current module. By observing the position of the Moon, Cal could predict the correct phase consistently. Cal could explain what he was seeing, but not why he was seeing it.

Design Request

Cal thought it would be prudent to have a quiz at the end of the sessions to see how well he had done. The researcher asked Cal if he would learn anything from his score about the phases of the Moon. Cal assured the researcher that he would learn a lot. He believed that if he was thinking incorrectly and nobody corrected him, he would go on forever believing the wrong things.

Post Session Journal Entry

The post journal entry was similar to the base entry. Cal described the phases of the moon similarly to how he described his initial theory. The views were drawn from the overhead perspective and surprisingly, the Earth and Moon were not correctly illuminated by the Sun. The journal entry did not correspond with Cal's observations and conclusions of the current microworld session.

Microworld Revision 2.0

Session Description

The researcher introduced the new quiz module to Cal. The quiz would display a view of the moon, and the user was required to select the appropriate phase (waning crescent, waning gibbous, waxing crescent, waxing gibbous, full, new). The user could test any description and watch the Moon orbit the Earth for that phase before providing the answer. The quiz would provide a correct or incorrect response and view feedback for incorrect responses. The number of correct and incorrect replies were maintained. Cal decided to use the microworld again before trying the exam.

Cal entered the shapes module and experimented with all shapes similar to his first session. A comparison of the cylinder and the sphere followed. Cal switched from one to the other several times. Cal stated that light could not bend around the top of flat objects. A comparison of the cylinder and sphere followed. For example, the eye and the light would be positioned at fixed locations. Cal would then swap the shapes to see the different views. Cal concluded that light does not bend at all. Cal then focused on the sphere and commented that it was similar to phases of the Moon as the eye or light was revolved about the shape. Cal tried to make the following analogy to reconcile the parallels between direct observations of lunar phases and the shapes module. Within the shapes module the shape is at a fixed location and the light revolves about the shape. Within the phases module, the light (Sun) is at a fixed location, and the object revolves.

The views module is next in Cal's preparation of the quiz. Cal experimented with different views similar to the first session. With each view Cal described the position of the Sun and reinforced his belief that the surface closest to the Sun is always bright. He noticed that the Moon orbits the Earth on a diagonal. Cal did not make this observation in the first session. The researcher reminded Cal about his eclipse theory and asked Cal to show him where the eclipse occurred. Cal paused and observed a few more views. Unable to provide an answer, he could not reconcile this conflict and wanted to move to the next module.

Similar to the first session, Cal could predict the lunar phase in any orbital position. Cal stated that the Moon is always half bright and the view depended upon "which side of the moon you were seeing." Cal tried to compare this module with the sphere in the shapes module but quickly became confused.

Excitedly, Cal moved on to the quiz module. He was pleased to see that the module kept track of correct answers. Cal was able to score well on the quiz and was quite pleased with the results. Cal could correctly predict the lunar phase based upon the position or Moon about the Earth, but could still not explain why the Earth did not cause an eclipse upon the Moon when positioned the farthest from the Sun.

Design Request

Cal requested two more oblique views of the Moon orbiting the Sun in the views module. Cal felt that with a few more views he could find out why the Earth did not cast a shadow on the Moon.

Post Session Journal Entry

The journal entry for revision 2.0 did not include any diagrams. Cal provided a verbal description of four different phases of the Moon (full, new, waning gibbous, waxing crescent). The verbal descriptions were correct but did not provide any insight to the causes of lunar phases.

Microworld Revision 3.0

Session Description

Following a brief introduction, Cal experimented with the new oblique views provided by the researcher. The new views did not offer any insights to Cal to explain why the Earth did not cast a shadow on the Moon when farthest from the Sun. Cal reinforced his observation that the surface closest to the Sun was always bright. He also noted that the amount of brightness and darkness changed with the views, similar to the phases module. When standing on the Sun, the Moon is always bright. When standing on Mars, the moon is always dark. From the sides, the moon is one half dark and one half bright. The new views that were provided from outer space (upper right and lower left) were similar to a crescent and gibbous Moon. Cal used the words "reflected light" for the first time in explaining the brightness. He stated, "It's the amount of light you see. I get it."

Cal wanted to move onto the phases module specifically to question the researcher about where he (Cal) was standing on the Earth (where was the X,Y view of the moon being observed). Cal moved the Moon about the Earth a few times. Cal then picked different phases for both the Moon orbits and the views from Earth. He stated that he thought he knew what was happening but was confused and could not relate his experience with the views module to the shapes module. Cal could not verbalize his confusion.

Design Request

Cal requested that the researcher provide another view in the shapes module. Cal and the researcher agreed that another "eye" could be programmed that would allow two different 360 degree views of the shapes. Figure 5.1 is an illustration of the new functionality.

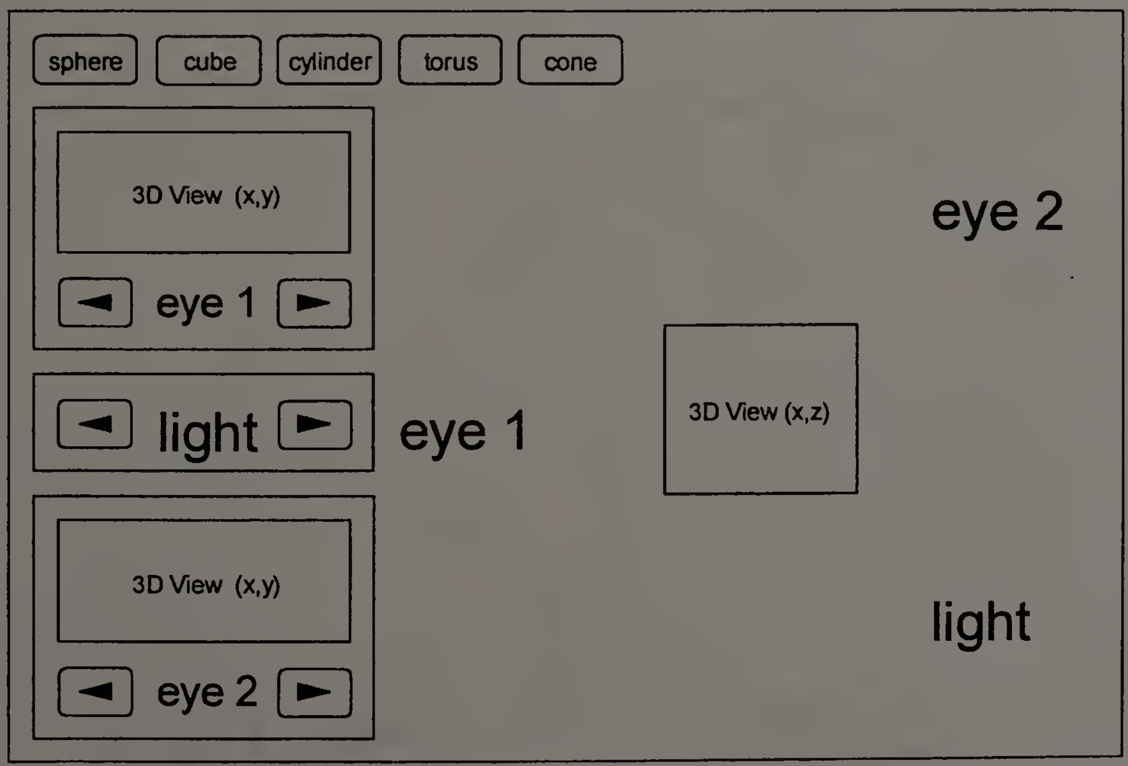


Figure 5.1: Multiple Shape Perspectives

Post Session Journal Entry

The journal entry was similar to the previous entry. There was a verbal description of the moon in each phase of the orbit but no explanation for causes of lunar phases. Again, Cal had a description of what was happening, but no explanation of why it was happening.

Microworld Revision 4.0

Session Description

After a brief introduction to the new dual view module, Cal did not play with the new functionality, he immediately placed the two "eyes" opposite each other and at a right angle to the light. This created reciprocal views with the sphere being half illuminated. In one view the right half was illuminated, while the left half was illuminated in the second view. Cal stated that this is what he thought he would see and that it was easier to "picture" it with two view.

Cal next moved to the views module, checked the view from each side of the Moon and appeared satisfied. He stated, "I saw what I wanted to see: opposites. The views were the same from both sides of the moon the same way they were from both sides of the sphere."

Cal's next step was to check his theory in the phases module. He moved the moon to opposite sides of the earth and perpendicular to the Sun creating waning gibbous and waxing crescent moons. Cal stated, "Yes, it's the same here too: opposites." Cal stated that the phases of the moon are caused by where you are standing. The researcher asked Cal if he had previously observed the moon from the same spot every night. Cal stated that most of the time it was from his home, but some of the time it was from a car.

When questioned why the Earth did not cast a shadow on the Moon, Cal stated that he thought it was something to do with the angle, but he was not sure.

Post Session Journal Entry

The journal entry was similar to the previous entries. A verbal description was defined for four different views detailing the lunar phases. For example, to explain a full moon Cal would write, "you would see this view when the Moon is directly behind the Earth." There was a mention of opposites when explaining a waxing gibbous moon.

Session Summary Table Description

The table reads left to right and top to bottom.

Table 5.1: Cal's Session Description

Session	ID	*	Behavior	Description
1.0	S	P	Cognitive Conflict	Non-illuminated cylinders and cubes in X,Z View.
1.0	S		Conjecture	Light cannot bend far enough to illuminate flat surfaces.
1.0	S	I	Inference	Light cannot bend to illuminate flat surfaces, but can bend to illuminate curved surfaces.
1.0	V	P	Conjecture	Half of the moon is always bright.
1.0	V	I	Cognitive Conflict	View from Mars shows Moon all Dark.
1.0	V	I	Inference	The side closest to the Sun is always bright.
2.0	S	P	Conjecture	Light does not bend around flat surfaces.
2.0	S	I	Inference	Light does not bend at all.
2.0	S		Analogy	Attempts an analogy with the phases module.
2.0	V	P	Conjecture	Surface closest to Sun is always bright.
2.0	V	I	Inference	Surface closest to Sun is always bright.
2.0	P	P	Analogy	Attempts an analogy with the shapes module.
3.0	V	P	Conjecture	The amount of brightness changes with the view.
3.0	V		Inference	You see the reflected light.
3.0	P	P	Analogy	Tried to make an analogy to shapes module, confused.
4.0	S		Conjecture	Opposing perspectives create reciprocal views.
4.0	S	I	Analogy	Views module provides the same behavior.
4.0	V	I	Analogy	Phases module provides the same behavior.
4.0	S	I	Inference	Opposing perspectives do create reciprocal views.

* P=Play I=Investigate

M* (Module) S=Shapes V=Views P=Phases R=Rocket

Domain Score Summary

Immediately following each session, a domain comprehension score sheet was recorded as described in Chapter 3 and illustrated in Table 3.1. Using the criteria described in Chapter 3, the researcher reviewed the current screen camera session and post session journal entry to assign a knowledge domain score. Figure 5.2 charts the knowledge domain comprehension and design request for each session. The gray bars indicate a comprehensive understanding for the specific knowledge area.

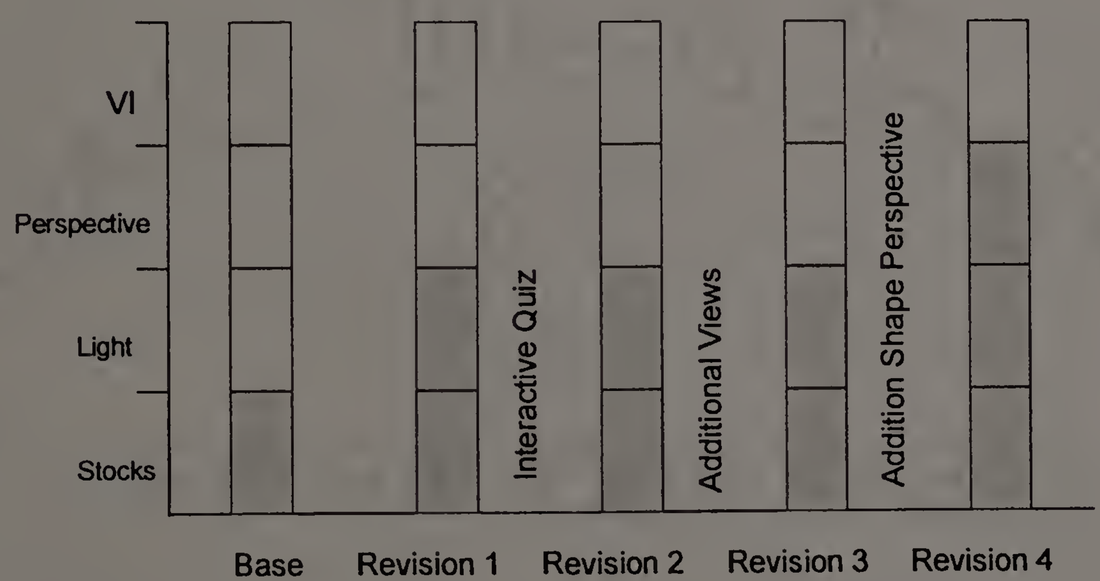


Figure 5.2: Knowledge Domain Assessment

5.2.2 Student Subject - Joe

Base Journal Entry

Following a two week observation of the moon, Joe documented the refraction theory described in Chapter 4 and illustrated in Figure 4.4. Similar to a pilot study student, this theory was an advancement of the eclipse theory when Joe realized the lunar cycles were inconsistent.

Microworld Revision 1.0

Session Description

Joe was the second of the five students that participated in this phase of the study. Joe was an outdoors man always dressed in camouflage fatigues and a hunting hat. He was very comfortable with the concept of thinking out loud and conversed openly with the researcher.

Joe investigated the shapes module playing with different shapes, views, and lighting angles. He compared the sphere to the moon and stated that the shapes he was viewing were exactly the same as the Moon. Joe stated, "When you see the Moon is all dark (new Moon), it is because you are smaller than the Moon and cannot see around it." As Joe moved the light he described the different views of the shapes as "angles of light, you only see the bent light from your eye."

Joe was surprised that he could not see the top of the cylinder in the overhead view. Joe immediately selected the cube, the cone, then the cylinder gain. Joe then stated that "flat surfaces do not allow the light to hit it." He pointed to each shape and correctly identified what he would and would not see in the X,Z view.

The views module was the next to be investigated. This module allowed students to view the Moon orbiting the Earth from multiple outer space perspectives. Joe investigated many views and then stated "half of the moon is always bright; it looks like somebody has taken a bite out of it (waning gibbous moon)." Joe looked at more views pointing out the direction of the Sun (the Sun was not visible in any of the views). He also stated that "the Moon orbited at an angle about the Earth, approximately 40 degrees." When viewing the Moon from Mars, Joe stated that "it looks like people do from the back when walking towards a campfire at night, you can only see the outlines." After checking many view perspectives, Joe declared that the Moon orbits at a diagonal from all of the views and that the Earth could not cast a shadow on the Moon.

The researcher asked Joe if he thought light could bend. Joe felt that in some cases light could bounce off the top of the Earth and cause a shadow on the Moon. He returned to the shapes module and experimented with a few shapes. Joe concluded that light does not bend because he could not find a view that would support this.

Joe next investigated the phases module (Chapter 4, Figure 4.11). After moving the Moon about the Earth a few times, he could explain waning gibbous and waxing crescent phases, correctly referring to the amount of light somebody would see. Joe was confused with the new and full Moon phases. In his explanation, he reverted to his theory that light bends. Joe tried to introduce angles into his explanation, but could not integrate his new observations with clarity.

Design Request

In the researcher's opinion, Joe asked for a very creative addition to the shapes module. He wanted more complex shapes that combined the existing simple shapes. Following a considerable amount of discussion, two shapes were agreed upon, a cube with a sphere affixed the top, and a cylinder with a cone of a smaller radius affixed the top. Joe was not sure what he expected to see, but thought the results would be interesting.

Post Session Journal Entry

The post journal entry was very different from his base entry. The views were drawn from the overhead perspective with multiple straight light rays as illustrated in figure 5.3.

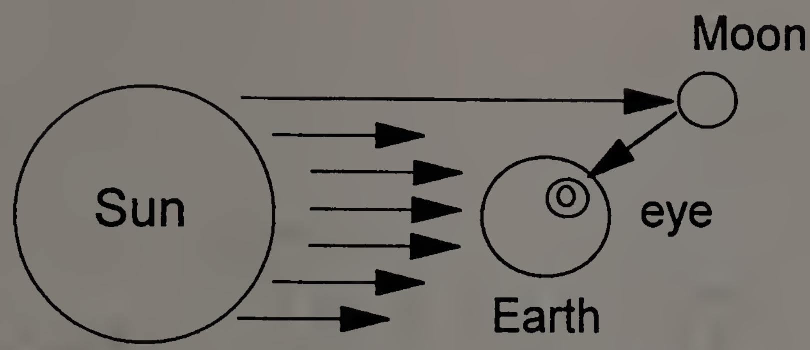


Figure 5.3: Joe's Post Session 1.0 Journal Entry

Joe correctly diagrammed all but the full and new phases of the Moon. He illustrated them backwards. Joe used the phrases "I think" and "Something to do with the angle," exhibiting less than absolute confidence in his explanations. It is interesting to note that Joe did not shade the Earth or Moon appropriately. The Earth and Moon were both fully illuminated. Joe's drawing included a concept of reflected light rays and the position on the Earth of the lunar perspective (eye).

<u>Microworld Revision 2.0</u>

Session Description

The researcher asked Joe if he had thought about phases of the moon since the last session. Joe said that he had, but it was hard because it took a whole day to see the changes. Joe was introduced to the new shapes. As Joe moved the light around the cube-sphere he stated that it looked just like a lighthouse from above. Joe commented that "the light bounces and reflects off the sphere back to the eye, but not from the flat surface (of the cube)." Joe checked the cylinder-cone and compared it to the cube-sphere pointing out the flat and angled surfaces. He picked other shapes and concluded that you only see reflected light and that flat surfaces cannot reflect light. The researcher asked Joe how the new shapes helped him develop his solution. Joe felt that the combined shapes helped him see two ideas at the same time. He also thought that a textured surface, like a rock, would help show the outlines (dark versus illuminated contours) better.

Joe skipped the views and moved on to the phases module. He moved the Moon about the Earth and correctly predicted all lunar phases including full and new Moons. Joe noticed that during a new moon, you could still see light rays about the surfaces. This is a phenomena known as Bailey's Beads (Marschall, 1996), where the texture of the landscape allows light to pass through valleys and to be viewed as a "bead of light." The researcher mentioned this to Joe and a prolonged discussion of landscapes and sunsets followed. Joe made many analogies to Bailey's Beads including the description of an outline of a tree at sunset. Joe was pleased that he made the same independent discovery as a scientist.

He was still confused with why the Earth did not cast a shadow on the Moon while farthest from the Sun (full Moon) while experimenting with the phases module. He believed that it had something to do with the angle. Joe jumped to the views module and experimented with many views. Joe showed a a view from the right side of the Moon and stated that "another light from above would be required to cast a shadow on the Moon."

Design Request

Joe felt that the phases view looked like "a piece of paper" and was confusing because the Moon actually traveled at an angle about the Earth. He wanted another simultaneous 3D view from outer space that showed the Moon traveling at an angle. Figure 5.3 is an illustration of the new functionality.

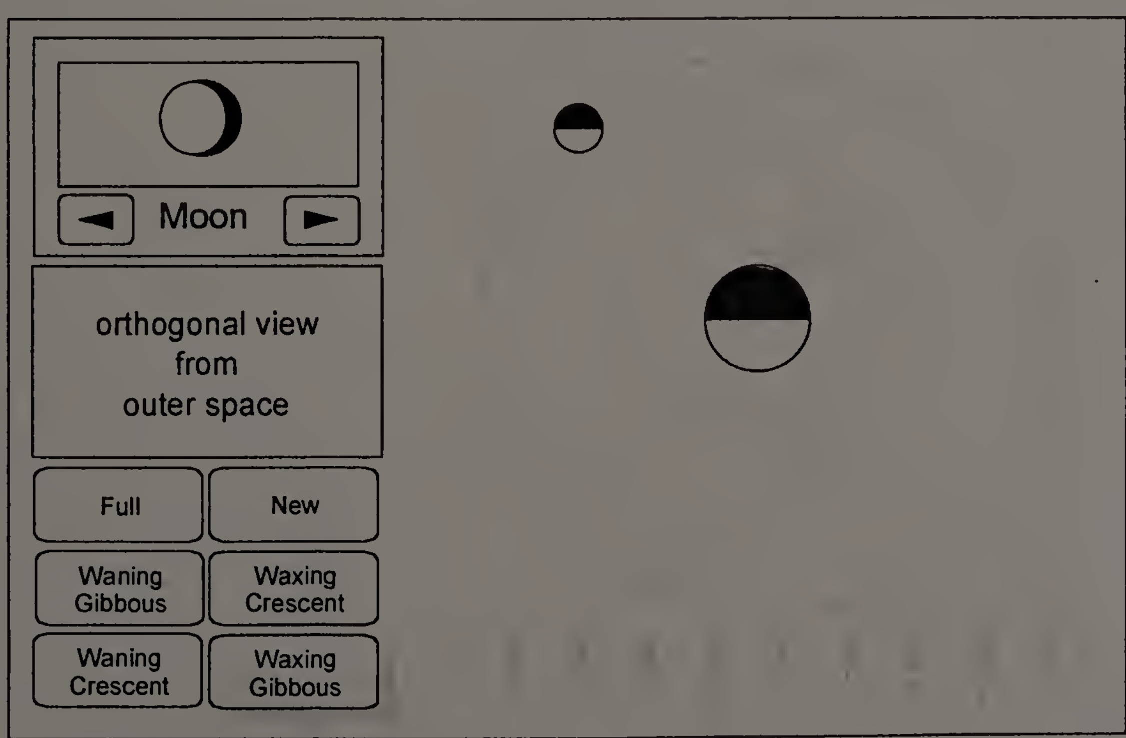


Figure 5.4: New Phases Module With Orthogonal View

Post Session Journal Entry

The journal entry for revision 2.0 was similar to the previous entry with two exceptions. The Moon was shaded correctly and an additional view supplied for each location of the Moon (similar to the phases module). There was no mention of diagonal orbits.

Microworld Revision 3.0

Session Description

Joe was introduced to the new orthogonal view in the phases module. Joe moved the Moon about the Earth and then played the full Moon sequence a few times. Joe stated that it was very clear why the Earth did not cast a shadow on the Moon. He took time to explain that during a full moon phase, the Moon was behind the Earth and above the Earth at the same time. This enabled the light to reflect off the Moon. Joe suggested that the Sun should be visible in the orthogonal view so that it would be obvious where you were standing when looking at the Moon.

Joe requested that in the next session he wanted to see what features other students had suggested. The researcher shared Roberta's navigational model (explained later in this chapter) in the views module with Joe. Joe felt that it was a very good suggestion and helped understand where you were standing when experimenting with views. Joe then suggested that the path of the Moon be drawn as it orbited the Earth. Joe stated "this would make it very clear, like a train track, you could see where a train is going to come from and where it is going to go." He felt that it would make it very obvious that the Moon traveled at an angle about the Earth.

Design Request

Joe requested that the path of the Moon be drawn as it orbits the Earth to clarify a diagonal orbit.

Post Session Journal Entry

The journal entry was similar to the last with detailed verbal descriptions for all phases. The description stated that the Moon was above the Earth during a full Moon. The Earth and Moon were shaded correctly illuminating the surfaces closest to the Sun and shading the surfaces furthest from the Sun.

Microworld Revision 4.0

Session Description

The researcher reviewed the modifications made to the views module that showed the path of the Moon. Joe was not interested in using the module but commented that it made it very clear that the Moon orbited on a diagonal about the

Earth. He felt that other students using the module would benefit from this change.

Joe had heard that Roberta had created rocket ship simulation that traveled to the Moon and back from the Earth and would like to see it. The researcher stated that it was just a fun activity to introduce students to the microworld and did not hold much educational value. Joe insisted that he would very much like to see it.

The rocket ship simulation was created using a virtual 3D world. The rocket slowly took off from the Earth and gradually gained speed as it headed towards the Moon. The rocket circled the far side of the Moon, headed back towards the Earth, circled the Earth, and landed where it began. The Sun provided appropriate lighting throughout the trip. The rocket ship viewing console could always see the Moon. In essence, it was as if the front of the rocket ship always pointed towards the Moon and returned to Earth backwards.

Joe watched the rocket's space flight twice. On the second trip, Joe stated that the rocket had caused the Moon to exhibit all of the phases. It was a full moon when the rocket first took off, transitioned to a new Moon as it traveled to the dark side, and back to a full Moon on the return trip home. Joe suggested that it took a month for the Moon to go through all of the phases and a rocket ship could create the same phases in just a few minutes. A time element was introduced to lunar phases and discussed at length with the researcher. Joe concluded that if the Moon revolved more quickly about the Earth, the phases would happen more quickly. Joe also compared the flight of the rocket ship with the shapes module. He stated that "the Sun was stationary like the light and the view was the same from the rocket ship to when you moved the eye around the sphere".

Post Session Journal Entry

There was no journal entry for the last revision.

Session Summary Table Description

The table reads left to right and top to bottom.

Table 5.2: Joe's Session Description

Session	M*	*	Behavior	Description
1.0	S	P	Cognitive Conflict	Tops of cylinder and cube are not illuminated.
1.0	S		Analogy	Sphere views look like the Moon phases.
1.0	S	P	Conjecture	Flat surfaces do not allow the light to hit it.
1.0	V	I	Analogy	The Moon looks like somebody has taken a bite out of it.
1.0	V	P	Analogy	View of Moon from Mars looks like a campfire scene.
1.0	V		Conjecture	Half the Moon is always bright.
1.0	V		Conjecture	The Moon orbits at a diagonal about the Earth.
1.0	V	I	Inference	The Moon looks like somebody took a bite out of it.
1.0	P	P	Cognitive Conflict	During the full Moon phase the Earth should be casting a shadow on the Moon.
1.0	P		Inference	Attempts but fails to introduce orbit angles.
2.0	S		Analogy	Compares cube-sphere X,Z view to lighthouse.
2.0	S	I	Inference	Light does not reflect on flat surfaces.
2.0	V		Incidental Learning	Discovery of Bailey's Beads.
2.0	V		Analogy	Analogy of Bailey's Beads to tree silhouette at sunset.
2.0	P	P	Conjecture	Non-eclipse during full Moon is related to angled orbit.
2.0	V	I	Inference	No conclusion stated.
3.0	P	P	Inference	Because of diagonal orbit, the Earth cannot cast a shadow on the moon.
3.0	P		Analogy	Compared a drawn path of the Moon orbiting the Earth
4.0	R	P	Incidental Learning	Discussion of time element and lunar phases.
4.0	R		Inference	Faster rotation of the Moon world cause faster lunar
4.0	R		Analogy	Compared the rocket ship to the eye in the shapes

* P=Play I=Investigate

M* (Module) S=Shapes V=Views P=Phases R=Rocket

Domain Score Summary

Immediately following each session, a domain comprehension score sheet was recorded as described in Chapter 3 and illustrated in Table 3.1. Using the criteria described in Chapter 3, the researcher reviewed the current screen camera session and post session journal entry to assign a knowledge domain score. Figure 5.5 charts the knowledge domain comprehension and design request for each session. The gray bars indicate a comprehensive understanding for the specific knowledge area.

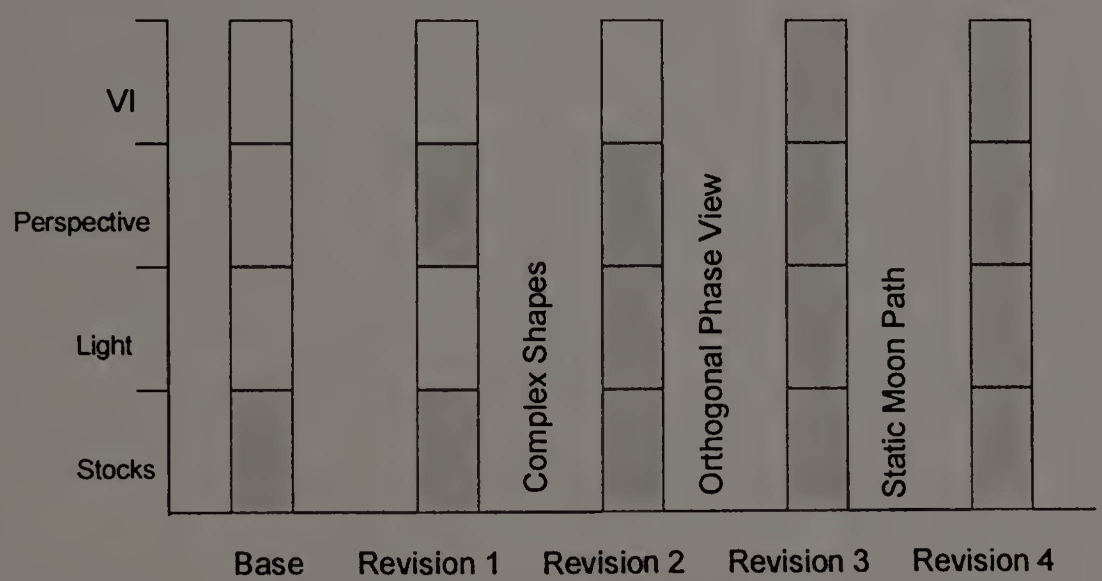


Figure 5.5: Knowledge Domain Assessment

5.2.3 Student Subject - Mark

Base Journal Entry

Following a two week observation of the moon, Mark documented the eclipse theory in his journal described in Chapter 4 and illustrated in Figure 4.2. Mark was the only student to document a crescent Moon with the tails pointing towards the sky as opposed to East / West. He was very detailed in his drawings and provided the most lengthy verbal descriptions.

Microworld Revision 1.0

Session Description 1.0

Mark was the third of the five students that participated in this phase of the study. Mark started with the shapes module. After a brief introduction by the researcher, Mark experimented by moving the light bulb, the eye, and changing shapes. Mark was very methodical and deliberate in his actions. The eye, then the light, would be revolved completely around each shape. Mark would then switch systematically between the eye and light for a given shape. After choosing the sphere, he stopped when it appeared half illuminated. He stated "this is exactly the opposite of what the moon looked like a few nights a go, if I move the light to the other side, it will appear the same." Mark could not understand why the entire object was not illuminated. His confusion was elevated when he could not see the top of cylinder or cube.

Mark had spent a lot of time with the shapes module and decided to move on to the views area. He experimented with the side and top views in the same manner that he interacted with the shapes; slow and methodical. After a few minutes, Mark stated that "the Moon appears the same but different, the Moon is always one half bright, but the views are opposite." He also noted that the moon revolved on a diagonal about the Earth and that "light traveled straight." Mark was very confused when he looked at the Moon from the Sun and Mars. The observed Moon was contrary to his initial conclusion, appearing either fully illuminated (from the Sun) or totally dark (from Mars). Mark wanted to see the phases module before time ran out for the current session.

Instantly, Mark wanted to know where he was standing on the Earth when looking at the X,Y view. The researcher stated that he was standing on the North pole. Mark stated "I think it makes a difference, but can't explain how." Mark revolved the Moon about the Earth a few times. During the full Moon phase he felt that the Earth should be casting a shadow on the Moon.

Design Request 1.0

Mark was very concerned with his perspective in the first session. He appeared to be confused between the different views. He wanted to clarify what the eye was seeing in the shapes module and where on the Earth he was standing in the phases module. The researcher provided visual feedback in the shapes module by highlighting the X,Y view every time the eye was clicked and placed a cross within the 3D world at the point on the Earth where the X,Y view of the Moon was observed.

Post Session Journal Entry

In his first journal entry, light was represented by one bent arrow, however, his verbal descriptions described an eclipse. In the journal entry following this session, light was represented by multiple straight rays emanating in all directions from the Sun. The verbal entries continued to describe an eclipse.

<u>Microworld Revision 2.0</u>

Session Description

Marks started the session be explaining to the researcher that light travels in a straight line, while he moved the eye about the shapes. He stated "the shapes are always half bright because light travels straight." Mark explained to the researcher that he had been watching the Moon and simulated the observed lunar phases by adjusting the light source about the sphere. He selected the cylinder and moved the eye 360 degrees explaining what he observed. He made no mention of the dark surfaces in the X,Z view.

Mark moved to the phases module. While moving the Moon about the Earth, he stated that "the Moon sometimes points up, not out like in this picture". Again he became confused during the full moon phase wondering why an eclipse does not occur. Frustrated, he asked the researcher to explain it to him. The researcher encouraged him to explore the views module to see if he can find the answer himself. Mark explored the views module for a few minutes experimenting with all perspectives. When observing the Moon from the side, Mark suddenly shouted "ooooh, it travels at an angle so that the light rays always hit the Moon, I knew that, I said that last time."

Mark confidently switched to the phases module and compared the X,Z view of the Moon orbiting the Earth to the top view within the views module. During the full Moon phase, Mark stated that the Moon looks like it is directly behind the Earth, but it actually travels on a diagonal.

Design Request

Although it was clear to Mark that the Moon travels on a diagonal, he wanted it to be clear in the phases module so it would be less confusing to other students. Following a considerable discussion, we decided that an outer space view would be better than a view from the Sun for relating a realistic view to new users.

Post Session Journal Entry

The post session journal entry was a verbal description emphasizing that that Moon orbits on a diagonal and that light rays only go straight. The entry is less confident than the experiences observed in the session. The entry ended with Mark writing "it still depends where you are looking at the Moon."

Microworld Revision 3.0

Session Description

Mark observed the new 3D view in the phases module and assured the researcher that it would benefit new users. He then decided he would like to review the shapes module. Authoritatively, he stated as he reviewed different shapes that light does not bend and that you cannot see the "flat tops" because light cannot reflect off these surfaces. He told the researcher, however, that he was confused because he could see into corners where direct light could not shine. "How does the light get there?" A lengthy discussion followed about light, reflection, colors, and shadows. Simple experiments were developed that would test some of the hypotheses at home.

Mark still felt that the Moon would look different depending upon where you were looking at it on the Earth. A second discussion took place about his observations. Did he observe the Moon at the same time every night? Did it look different at the same time on different nights? Did he always observe the Moon from the same location? Mark and the researcher agreed that the next microworld iteration would allow him to observe the Moon from different positions on the Earth.

Mark queried the researcher why he did not spend much time explaining the word descriptions for lunar phases (waning, waxing, gibbous, crescent, full and new). The researcher assured Mark that it was important to first understand the causes of lunar phenomena prior to learning the definitions of lunar phases.

Design Request 3.0

An open ended request to provide any arbitrary view from Earth of lunar phases was beyond the time extent of this study and could no be incorporated in the existing microworld. The researcher decided to create a model of the Earth, Moon, and Sun that would allow Mark to work directly within the virtual world.

Post Session Journal Entry

Mark's post session journal entry was the most complete and descriptive to date. For the first time, a three dimensional picture was drawn showing the diagonal orbit of the Moon. Mark talked about reflected light rays off the Moon at different lunar phases. For each example he explained where on the Earth the Moon was being observed, the correct illumination and shading of the Moon, along with a second view port showing the reflected light as viewed by the individual. Non illuminated areas of the Moon were not referred to as shadows, but as darkness, implying the absence of light.

Microworld Revision 4.0

Session Description

The researcher introduced Caligari TrueSpace 3.0 to Mark explaining concepts of dimensional camera views. Mark wanted to try multiple camera views from outer space, on top of the Earth,
and in front of the Earth. The camera angles from all three locations produced similar views found in the microworld.

Illustration 5.4 shows an example of two camera locations. Mark was sure he would see the Moon with the tails pointing up and was quite disappointed when none of the views produced the expected results. The researcher suggested that the camera to the left in illustration 5.4 be revolved 90 degrees to the left.

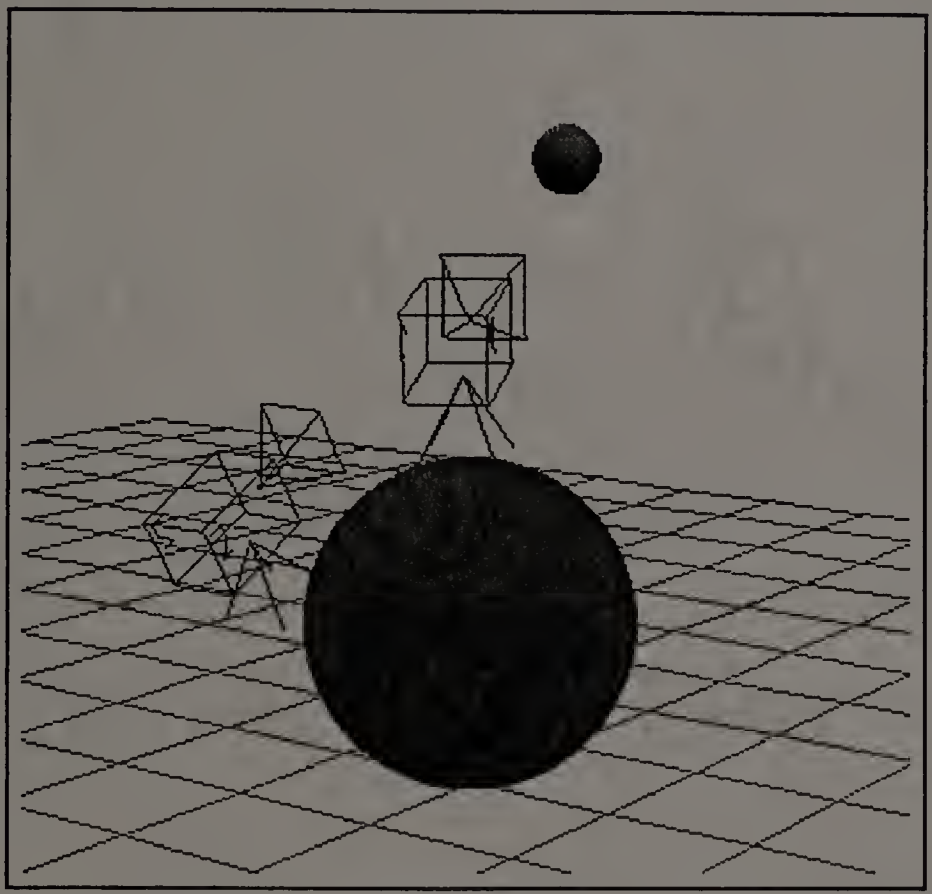


Figure 5.6: Camera Angles From Views On Earth

The rotation produced a view containing a crescent Moon with the tails pointing straight up. Mark was very excited stating that this was not quite what the Moon looked like that he observed, but very close. The researcher experimented with the position of the camera until the Moon appeared exactly as Mark had observed. Followed the experiments, a discussion of gravity and why the camera actually would not have to be tilted on the Earth to recreate the observed behavior. Mark questioned what the Moon would look upside down from the South Pole. We had run out of time. Mark was very interested in what other designs students had generated.

Post Session Journal Entry

There was no journal entry for the last revision.

Session Summary Table Description

The table reads left to right and top to bottom.

Table 5.3: Mark's Session Description

Session	M*	*	Behavior	Description
1.0	S	P	Cognitive Conflict	Tops of cylinder and cube are not illuminated.
1.0	V	P	Conjecture	The Moon appears the same but different, the Moon is always one half bright, but the views are opposite.
1.0	V		Conjecture	The Moon traveled on a diagonal about the Earth.
1.0	V		Conjecture	Light travels straight.
1.0	V		Cognitive Conflict	Views from Mars and the Sun appear contrary to belief that Moon is always half illuminated.
1.0	V		Conjecture	I think it makes a difference where you are standing on
1.0	P	P	Cognitive Conflict	Does not understand why there is not an eclipse during
2.0	P		Conjecture	The shapes are always half bright because light travels
2.0	P		Analogy	Creates observed lunar phases with sphere and light in shapes module.
2.0	P		Cognitive Conflict	The Moon sometimes points up, not out like in this
2.0	P		Cognitive Conflict	During the full Moon phase the Earth should be casting a shadow on the Moon.
2.0	V	I	Inference	The Moon orbits at a diagonal about the Earth allowing the light to hit it all the time.
2.0	V		Analogy	Compares the X,Z view in the phases module to the top view in the views module.
3.0	S		Cognitive Conflict	If light does not bend, how can you see into the corners of a house?
3.0	S		Incidental Learning	Discussion about light, reflection, colors, and shadows.
3.0	P		Conjecture	It makes a difference where you are standing when you observing lunar phases.
4.0	3D		Conjecture	What causes the Moon to point up.
4.0	3D	I	Inference	Different positions on Earth result in different Views.
4.0	3D		Incidental Learning	Discussion about Gravity.
4.0	3D		Incidental Learning	Discussion about South Pole lunar views.

* P=Play I=Investigate

M* (Module) S=Shapes V=Views P=Phases R=Rocket

3D=Caligari

Domain Score Summary

Immediately following each session, a domain comprehension score sheet was recorded as described in Chapter 3 and illustrated in Table 3.1. Using the criteria described in Chapter 3, the researcher reviewed the current screen camera session and post session journal entry to assign a knowledge domain score. Figure 5.7 charts the knowledge domain comprehension and design request for each session. The gray bars indicate a comprehensive understanding for the specific knowledge area.

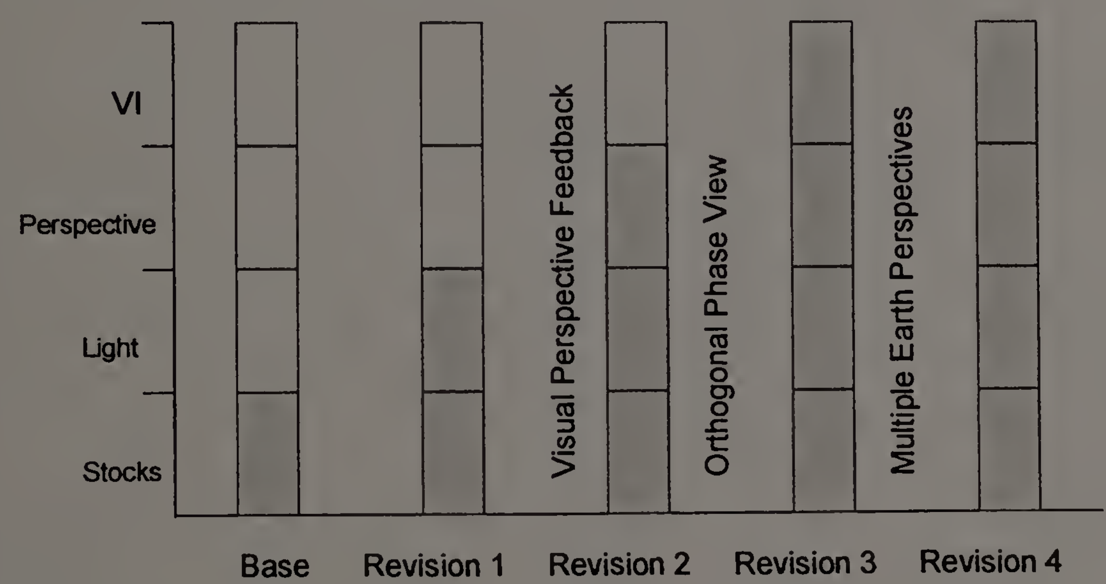


Figure 5.7: Knowledge Domain Assessment

5.2.4 Student Subject - Roberta

Base Journal Entry

Roberta's base journal entry contained a diagram that documented an eclipse theory of lunar phases. Different from other diagrams, sunlight was represented by multiple straight lines emanating in all directions as opposed to a single ray.

Microworld Revision 1.0

Session Description

Roberta was the most computer literate of all the students in the study. She frequently talked about programming in QBasic and other scientific activities that she participated in. On one occasion when the researcher was late to a session, Roberta independently set up the equipment, booted the system, and was interacting with the microworld.

Roberta' first session with the microworld was similar to previous sessions. She investigated all shapes within the phases module. She was confused by the non-illuminated flat surfaces of the cylinder and cube. Roberta was also surprised that the sphere and cylinder looked differently in the X,Y view. She was sure that they would look the same. She compared the sphere to the Moon when describing different views as he moved the eye or light. Roberta never mentioned that light may bend.

Within the views module, Roberta was surprised by the view of the Moon from the Sun. She stated "I just never knew what the Moon looked like from the Sun; I have never thought about it." Roberta spent a significant amount of time trying all views within the module. In each case she would point out the direction of the Sun, path of the orbit, and description of the Moon. She noted that the Moon traveled at a diagonal about the Earth and stated "this proves it, the Moon never goes directly behind the Sun." He volunteered that her original theory was incorrect. Roberta also compared two views with the flashlight and sphere from the shapes module.

Roberta next interacted with the views module. As she moved the Moon about the Earth, Roberta compared what she was seeing to the sphere within the shapes module. Her descriptions refer to the "amount of light you see" (hair, sliver, tad bit, more). She was not confused during the full moon phase and did not take the time to confront her initial theory. Roberta asked the researcher if her session was good or bad.

Design Request

Roberta felt the she would like to have explored the phases section prior to the views or shapes module. She felt that this provided the "big picture" and the other modules provided details. Roberta felt that a model of the galaxy would help her define where she was when looking at the views. The researcher and Roberta agreed to provide a model of the pertinent entities (Sun, Moon, Earth, and Mars) illustrated in Figure 5.5. This model was placed beneath the view buttons within the views module and revolved to the correct perspective each time a new view was selected.

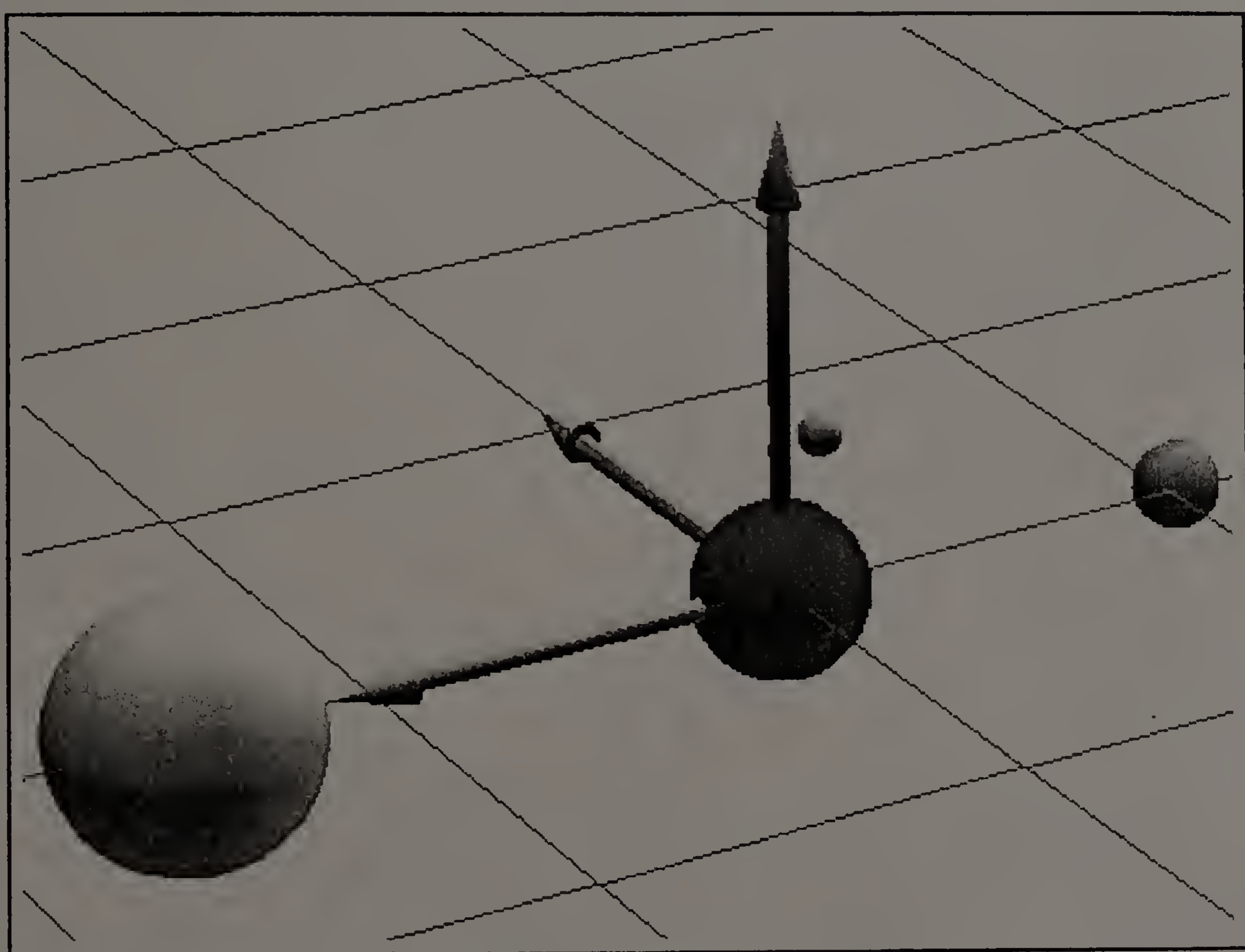


Figure 5.8: Navigation Model

Post Session Journal Entry

Roberta did not provide a journal entry for this session. Her teacher had warned the researcher that although she was a very bright student she was not reliable for work conducted outside of class.

Microworld Revision 2.0

Session Description

The researcher reviewed the new navigational model within the views module with Roberta. Roberta became extremely excited stating that it was exactly what she wanted. She felt that it made it very clear where in the universe she was when looking at different views. Roberta wanted to know how the researcher programmed three dimensional models. She wanted to compare the method with her Qbasic programming experience. A significant discussion of 3D modeling worlds followed.

Roberta selected the view form the Earth and wanted to know why she didn't see the Sun or Mars in real life. Some explanation may be necessary at this point. Most students did not select the view from Earth. All other selections within this module provided a view of the Moon rotating about the Earth from a static camera located in outer space. When viewing the Moon from Earth, the camera was dynamic, tracking the Moon through 360 degrees of rotation. All phases of the Moon could be seen as it was tracked by the camera (the Earth could not be seen because the camera was located on top of it). During the full and new moon phases, Mars and the Sun respectively could be viewed in the distance. A lengthy discussion followed comparing models with reality, outer space views versus real world views, and true distances between planets.

Roberta moved onto the phases module and flawlessly explained lunar phases, diagonal orbits, and reflected sunlight. She compared the reflected sunlight to the sphere and flashlight within the shapes module. When the researcher stated that it sounded as if she had rehearsed the explanation, Roberta responded that she had explained the phases of the Moon to her mother a few times.

Design Request

Roberta felt that it would have been less confusing if another view in the phases module showed the Moon traveling at a diagonal. This enhancement was similar to Joe's request for an orthogonal view illustrated in Figure 5.3. However, Roberta felt that the view from the Sun would be more helpful than the view from outer space. It specifically showed that the Earth does not cast a shadow on the Sun during a new Moon.

Post session Journal Entry

The post session journal entry was a very short one sentence verbal description that described lunar phases. It was incomplete and did not provide any insight to Roberta's understanding of lunar phases.

Microworld Revision 3.0

Session Description

Roberta started the third session with the phases module. She stated that one of the other students had mentioned that light bends. She thought this was silly because if light bends, it would be light all the time everywhere. Robert moved the eye about the Sphere and attempting to recreate an example similar to the phases module. She stated that she would not move the flashlight because the Sun is stationary. Moving the eye about the sphere produces the same effect as moving the sphere about the eye. This was similar to moving the Moon about the Earth. Roberta started to talk about time as being a factor with phases of the Moon but could not verbalize her thoughts to make sense. A discussion followed without any conclusions.

Roberta was very bored with the microworld and wanted to move on to something new. The researcher asked her to give him suggestions that would help other students understand lunar phases. Roberta felt that another perspective in the shapes module would enable students to see two views at the same time. He felt that you would not have to keep remembering what the last view looked like.

The design request for an additional view within the phases module was shown to Roberta. She concluded that it made it very clear that the Earth could never cast a shadow on the Moon. She felt it was better than the orthogonal view because it was less confusing. The researcher agreed that the orthogonal view could be misinterpreted and did not directly show the perspective from the Sun.

Roberta asked if we could develop a simple model in the 3D world next time we met.

Design Request

Roberta'a design request, another view in the shapes module, was similar to Cal's request illustrated in Figure 5.1. This modification would have been shown to Roberta immediately, however, time had expired for the current session.

Post Session Journal Entry

The researcher began the forth session by checking the journal entry for the third session. As suspected, it was blank. The researcher insisted that Roberta describe lunar phases the same way she explained it to her mother. He asked her to draw a picture to assist her in her explanations. Roberta drew a two dimensional picture from above the Earth correctly shading the Moon in four different locations (full, new, waning and waxing gibbous). The orbital path of the Moon was specified along with a verbal description of the diagonal characteristics. For each Moon location, another view next to it as seen from Earth was drawn. Roberta explained that light always shines off the Moon even when it is the farthest from the Sun. The earth was not shaded correctly, however, specific attention was made to point out the land and sea. Her illustration is shown in Figure 5.6.

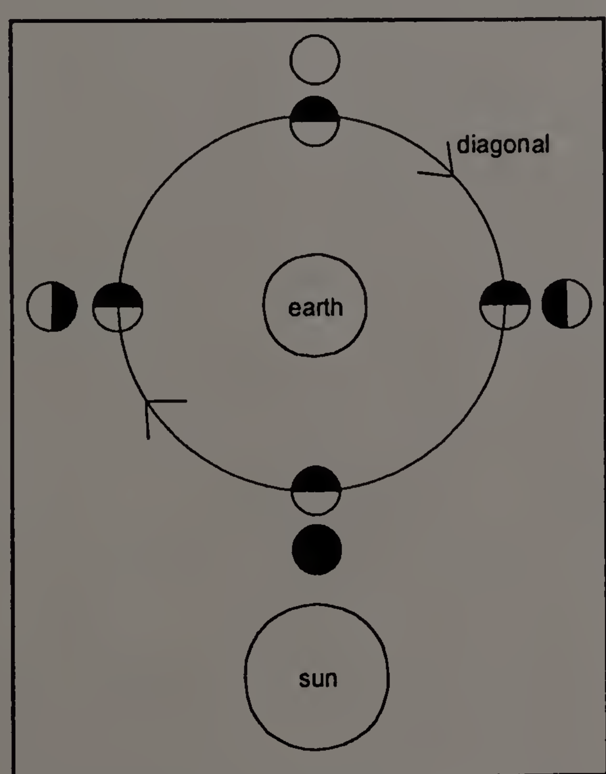


Figure 5.9: Roberta's Journal Entry Session 3.0

Microworld Revision 4.0

Session Description

Following the review of the journal entry, the additional perspective to the shapes module was shown to Roberta. Roberta was confident that this would help new students learn about phases of the Moon by provided two views at the same time. Roberta stated that you would not have to remember what the last view looked like when looking a new view. Roberta was more interested in investigating the new 3D microworld than continuing with lunar phases.

Roberta and the researcher quickly re-created a model of the Earth, Moon, and Sun. Dimensional views and light sources were investigated. Roberta was very interested in camera views and wanted to know if the camera could move similar to the planets. Discovering that cameras could move about a predefined path, she mentioned that it would be "cool" if we could make it look like a space flight from a rocket. After experimenting with different paths and views, a primitive space flight simulation was created. Roberta thought that a space flight introduction to the microworld would get students interested right away and be fun. The researcher agreed to create a more realistic space flight and incorporate it in the microworld.

Post Session Journal Entry

There was no journal entry for the last revision.

Session Summary Table Description

The table reads left to right and top to bottom.

Table 5.4: Roberta's Session Description

Session	M*	*	Behavior	Description
1.0	S	P	Cognitive Conflict	Tops of cylinder and cube are not illuminated.
1.0	S		Cognitive Conflict	Sphere and cylinder should appear the same in X,Y
1.0	V	P	Cognitive Conflict	Confused with the view of the Moon from the Sun.
1.0	V		Inference	The Moon travels on a diagonal about the Earth.
1.0	V		Analogy	Compares views to sphere in shapes module.
1.0	P		Analogy	Compares phases to views and shapes module.
2.0	V		Incidental Learning	Interested in 3D modeling environments.
2.0	V	P	Incidental Learning	Comparison of real world versus modeled world
2.0	P		Analogy	Compares lunar phases to shapes model with sphere and light bulb.
3.0	S		Cognitive Conflict	If light could bend, it would be light all the time
3.0	S		Inference	Recreates phases module with shapes module.
3.0	S		Analogy	Time was a factor with lunar phases.
4.0	3D	P	Incidental Learning	Dimensional and camera views within a 3D modeling environment

* P=Play I=Investigate

M* (Module) S=Shapes V=Views P=Phases R=Rocket

Domain Score Summary

Immediately following each session, a domain comprehension score sheet was recorded as described in Chapter 3 and illustrated in Table 3.1. Using the criteria described in Chapter 3, the researcher reviewed the current screen camera session and post session journal entry to assign a knowledge domain score. Figure 5.10 charts the knowledge domain comprehension and design request for each session. The gray bars indicate a comprehensive understanding for the specific knowledge area.

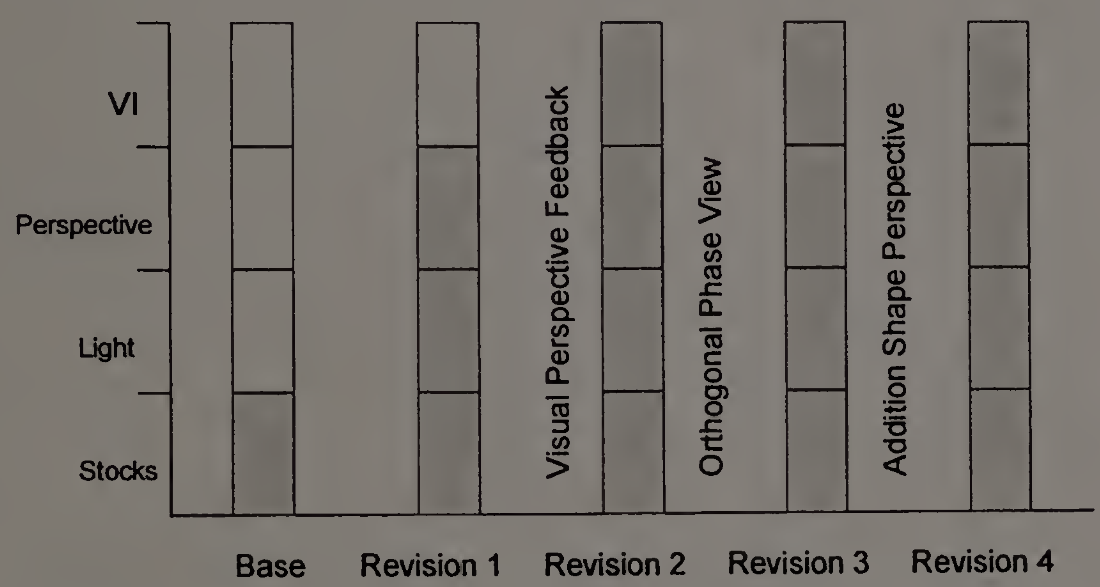


Figure 5.10: Knowledge Domain Assessment

5.2.5 Student Subject - Norm

Base Journal Entry

Norm's base journal entry contained a three dimensional diagram that documented an eclipse theory of lunar phases. Norm did not draw any light rays or shade the Earth and Moon appropriately to represent correct lighting.

Microworld Revision 1.0

Session Description

Norm's first session with the microworld was very similar to other sessions. He initially investigated the shapes module comparing the flashlight to the Sun and the sphere to the Earth. He described the amount of light and darkness that is seen while moving the eye about the sphere. He was initially surprised when the cylinder was chosen and he could not see the top surface within the X,Z view. After a few moments he stated that "you cannot see the top of the cylinder because there is no down light to light it up. You can see the side because the light is not at a slant. If the light was slanted down, you could see the top." When asked if light bends he replied, "light does not bend unless it hits something, then it bends back at you."

Norm investigated the views module next. He tried all the side and top views commenting that the Moon and Earth are always one half bright. He was surprised that the Moon travels at a diagonal about the Earth. He looked at the Moon from the perspective of the Sun and then from Mars. The view from Mars confused him and he stated that "I guess I am seeing the shadow of the Moon, it sort of looks like when you are working on the back of a computer with bad lighting and can only see the outline."

To end the session, Norm explored the phases module. He described exactly what he was seeing as he moved the Moon about the Earth. He was surprised to see a full Moon where he thought he would see a new Moon.

Norm stated that he wanted to look at the views module again. He commented that "I'm not sure what I'm looking for, I just want to observe it for a while." He tried all of the views again. Time runs out as Norm is exploring the views module.

Design Request 1.0

Norm wanted to make the shapes module more realistic by having the ability to turn the light off and on. He felt it would be more like a dark room when you entered and that you could see that parts of the shapes that were illuminated immediately upon turning on the light.

Post Session Journal Entry

The post session journal entry was diagrammed using an overhead view. It was very similar to the X,Z view in the phases module, but did not explain the full or new Moon phases. Norm illustrated light as parallel straight arrows emanating from the Sun in the direction of the Earth. The Moon was shaded incorrectly similar to examples of the eclipse theory illustrated in Figure 4.2 in Chapter 4. The Earth was not shaded.

Microworld Revision 2.0

Session Description

Norm felt that the light switch was very "cool" and worked exactly as he wanted it to. When asked how this helped him in learning about lights and shapes, he could only state that it was more realistic to come into a room with the lights turned off.

Norm continued to explore the shapes module and predicted the shape surfaces he would and would not see. When his predictions turned out to be true, he voiced "this proves it, light cannot bend unless it hits a mirror." Norm explained this concept making an analogy to pencils hitting the wall and bouncing back. The "pencils" did not hit the flat surface "walls" facing the ceiling, so they could not bounce back to you. He continued, "If there was a mirror on the ceiling, the light would bounce off the mirror onto the flat surface, and back again."

The researcher asked why the curved surfaces could be seen from above and the sides. Norm explained this in a very unusual manner. He said, "light bounces back like somebody saying hello to you after they see you. For example, if you had a lot of people located all over the ball, like sensors, and they could only say hello if they saw me, and I started walking around the ball, those people saying hello is what I would see. People on one side would say hello but not the other."

Norm transitioned to the phases module. He moved the Moon about the Earth and explained what he saw. The researcher asked why the Earth does not cause an eclipse during the full Moon phase. Norm responded, "because it is at a slant, I told you that last time we met and I thought it was important. I am sure that this is the reason." Norm switched to the views module, experimented with the side views, and then assured the researcher that this is the case.

Norm was asked by the researcher if the Moon appears differently as it revolves about the Earth. Anxiously, Norm stated that, "it is always the same, one half bright, but what you see is different." He pointed out the top view showing the researcher that it is always half illuminated as he moved the Moon. He then pointed out the X,Y view of the Moon showing that the appearance changes as he revolved the Moon about the Earth.

Design Request

Norm wanted a three dimensional view of the phases module to show that the Earth does not cast a shadow on the Moon. The researcher and Norm agreed that the views module already showed this and that an additional orthogonal view of the Sun, Moon, and Earth in the phases module may accomplish this request.

Post Session Journal Entry

The post session journal entry was not completed for this session.

Microworld Revision 3.0

Session Description

Norm reviewed the phases module that included the new orthogonal view. As Norm moved the Moon about the Earth, he stated that the Moon always appears the same, but the view of the Moon changes. He also felt that it was very obvious that the Earth did not cast a shadow on the Moon and the new view from outer space demonstrated this. After a few more trials, Norm suddenly stated, "No matter where you are in the universe, the Moon is always half bright and half dark, whether you can see it or not. It is where you are looking at it from that creates the phases." Confidently, Norm changes to the views module and supports his statement through examples.

Norm switches quickly between views and tentatively states that the rotation of the Sun can create the Moon phases more quickly. He could not verbalize his idea and quickly became confused. Norm played with the shapes module investigating differing eye perspectives using the sphere.

Design Request

Norm did not have any ideas for another revision; however, it was obvious to the researcher that Norm had a question that he could not verbalize. The researcher asked Norm for suggestions to the microworld that would help other students understand lunar phases that confused him. Norm suggested that the shapes module could have two "eyes" that would allow a student to see the shape from two different perspectives. He felt this would make it obvious that it was where you were looking at the shape (Moon) that made the phases.

Post Journal Entry Revision

Norm's post session 3.0 journal entry include two views illustrated in Figure 5.7. It is interesting to note that Norm did not shade the Earth appropriately, or draw light rays in his full Moon view.

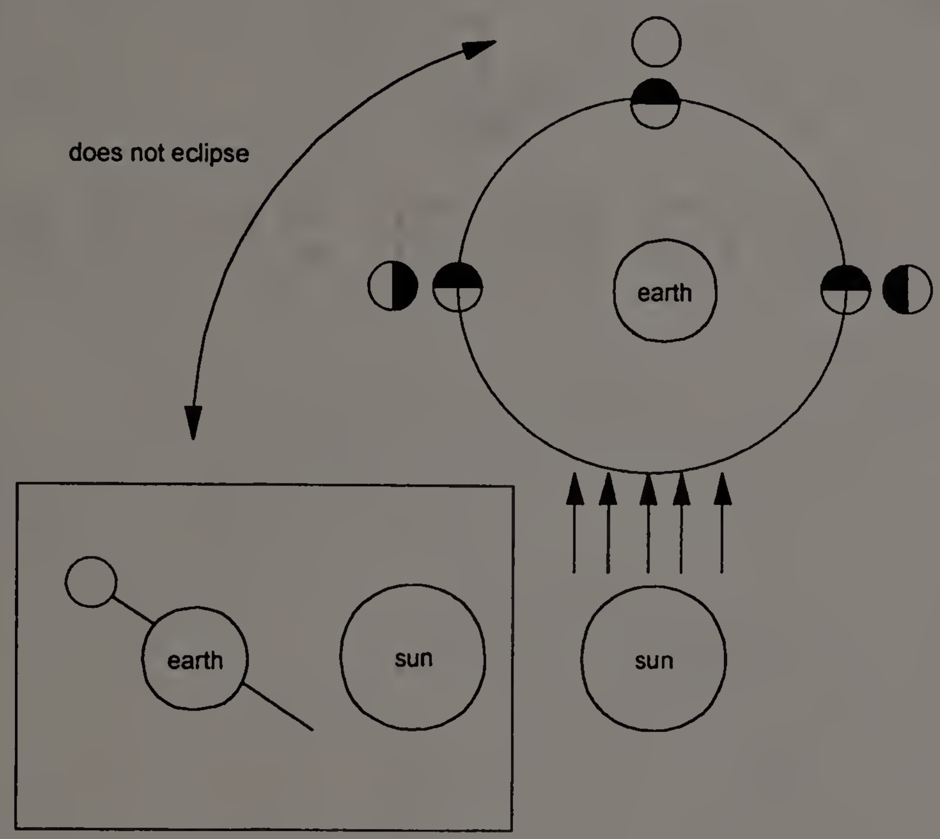


Figure 5.11: Norm's Journal Entry Session 3.0

<u>Microworld Revision 4.0</u>

Session Description

Norm was very interested in the two view perspective within the shapes module. While he was experimenting with the new functionality, he stated that, "phases have something to do with time. I can freeze time by looking at it from two different views. If I could move the eyes really quick, I could make the phases happen fast. I could have a lot of views at the same time and a lot of phases, but I can only be at one place at a time."

By now, Roberta's rocket ship was legendary and Norm wanted to see it. The second time that Norm launched the rocket and the path started to orbit the Moon, he told the researcher that, "this is what I was talking about, the Moon stays the same, but the phases are appearing because I am traveling around the Moon. If the rocket ship was faster, you could see lunar phases instantly." Norm spent the rest of his time talking about possible navigational and control features of the rocket.

Post Session Journal Entry

There was no journal entry for the last revision.

Session Summary Table Description

The table reads left to right and top to bottom.

Table 5.5: Norm's Session Description

Session	M*	*	Behavior	Description
1.0	S	P	Conjecture	Light only bends directly back at you.
1.0	V	P	Cognitive Conflict	Confused with the view of the Moon from Mars
1.0	V		Analogy	Compares view from Mars to bad lighting when working on the back of a computer.
1.0	P	P	Cognitive Conflict	Views a full Moon where he believes there should be a new Moon.
2.0	S	I	Conjecture	Flat surfaces do not reflect light.
2.0	S	I	Inference	Flat surfaces do not reflect light.
2.0	S		Analogy	Compares pencils bouncing of surfaces to light.
2.0	S		Analogy	Compares light to human voice sensors.
2.0	P		Conjecture	Earth does not cast a shadow on the Moon because of diagonal orbit.
2.0	P	I	Inference	Sun always illuminates Moon based on diagonal orbit.
2.0	P		Conjecture	Moon always looks the same, but appears different.
2.0	P	I	Inference	Moon is always half illuminated, but a person only sees a portion of the reflected light.
3.0	P	I	Inference	The Earth does not cast a shadow on the Moon.
3.0	P		Conjecture	No matter where you are in the universe, the Moon is always half bright and half dark.
3.0	V	I	Inference	It is where you are looking at it from that creates the
3.0	S		Conjecture	If the Sun revolved faster, the lunar phases would happen more quickly.
4.0	S	P	Conjecture	There is a time element associated with lunar phases.
4.0	3D	P	Inference	The faster the rocket ship, the faster the lunar phases.

* P=Play I=Investigate

M* (Module) S=Shapes V=Views P=Phases R=Rocket

Domain Score Summary

Immediately following each session, a domain comprehension score sheet was recorded as described in Chapter 3 and illustrated in Table 3.1. Using the criteria described in Chapter 3, the researcher reviewed the current screen camera session and post session journal entry to assign a knowledge domain score. Figure 5.12 charts the knowledge domain comprehension and design request for each session. The gray bars indicate a comprehensive understanding for the specific knowledge area.

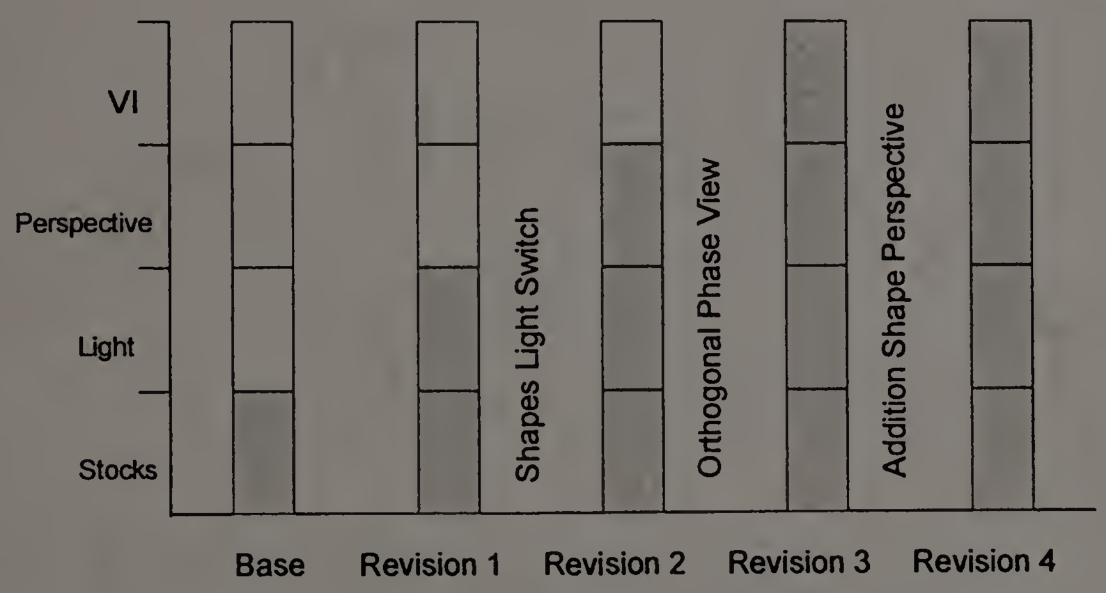


Figure 5.12: Knowledge Domain Assessment

5.3 Design Synthesis

Three significant learner-initiated designs were integrated into Revision 2.0 the microworld. Requested by three learners, the additional "eye" perspective illustrated in Figure 5.1 was included in the final revision of the microworld within the shapes module. Requested by four learners, an orthogonal view from outer space illustrated in Figure 5.3 was included in the final revision of the microworld within the phases module. Requested by one learner, the perspective model illustrated in Figure 5.5 was included in the final revision of the microworld within the views module. Many of the learners had difficulty with the perspective of the views in this module. The researcher considered this implementation the best alternative of two submitted by participants.

5.4 Microworld Revision 2.0

Five learners observed lunar phases for two weeks prior to documenting initial theories into their personal journals. Each student was allowed forty minutes to interact with the microworld and documented post journal theory entries immediately following the session. Learners were instructed to "think out loud" while exploring the microworld. To discretely describe all sessions would be a reiteration of many of the experiences described in the previous section. The following descriptions will highlight the significant differences discovered by the researcher within this group.

5.5 Sessions Overview

5.5.1 Base Journal Entries

Analysis of the base journal entries resulted in four students documenting the eclipse theory and one student documenting the obstruction theory.

5.5.2 Complex Environment

Revision 2.0 of the microworld was significantly more complex than revision 1.0. The researcher spent considerably more time explaining the functionality of multiple view perspectives in the shapes and phases module. The additional views initially created more confusion than assistance in comprehending lunar phenomena. Similar to the revision 1.0 sessions, learners were very concerned about providing the correct answer, asking permission to change modules, and finishing quickly.

5.5.3 Cognitive Dissonance

Similar to the initial learner sessions, cognitive dissonance was attributed to the following microworld qualities:

- Flat surfaces of the cube and cylinder within the phases module.

- Views of the Moon from the Sun and Mars.
- Non-eclipse of the Moon during the full Moon phases within the views module.

All five students interacting with revision 2.0 of the microworld experienced one or more of these conflicts. Two of the five learners believed that light could bend.

5.5.4 Analogies

All five learners made analogies to observations within the modules similar to students interacting with revision 1.0. Two students made analogies external to the modules using real life experiences:

- Comparing the view of the Moon from Mars to silhouettes on the horizon during sunset.
- Comparing the view of the Moon from Mars to looking into a lighted house at night.

5.5.5 Session Characteristics

The learner started each module with an exploration phase followed by investigations initiated by either cognitive conflict or self imposed conjectures. The majority of the time spent by learners in this session were exploratory. Most investigative actions were initiated by cognitive conflict. Learners would compare observed behaviors in adjacent modules to support conjectures.

5.5.6 Incidental Learning

There were no observed incidents of incidental learning for subjects in these sessions.

5.5.7 Post Session Journal Entries

Two of the five students correctly documented the causes of lunar phenomena. One of the five students correctly documented waning gibbous, waning crescent, waxing gibbous, and waxing crescent phases. The full Moon and new Moon phases were documented incorrectly. The documentation of two students did not change significantly from their base journal entries.

CHAPTER 6

DISCUSSION

6.1 Overview

This chapter discusses (1) the findings relevant to the research questions presented in chapter 1, (2) suggestions for future research, (3) implications for teaching strategies, and (4) the significance of the study.

6.2 Research Questions

6.2.1 Question 1

1. As learners interact with the experimental lunar microworld, what aspects of student cognition can be identified?

The following cognitive domains, specific to lunar phenomena, were successfully identified and tracked during the course of this study through the analysis of microworld sessions and journal entries.

* Identification of domain components
* Basic light properties
* Visual perspectives
* Phenomenological vs. variable independent analyses

6.2.1.1 Weekly Genesis of Student Learning

Figure 6.1 represents a frequency count of three of the initial lunar theories (obstruction, eclipse, refraction) devised by students prior to microworld usage.

Frequency of Theories by Revision

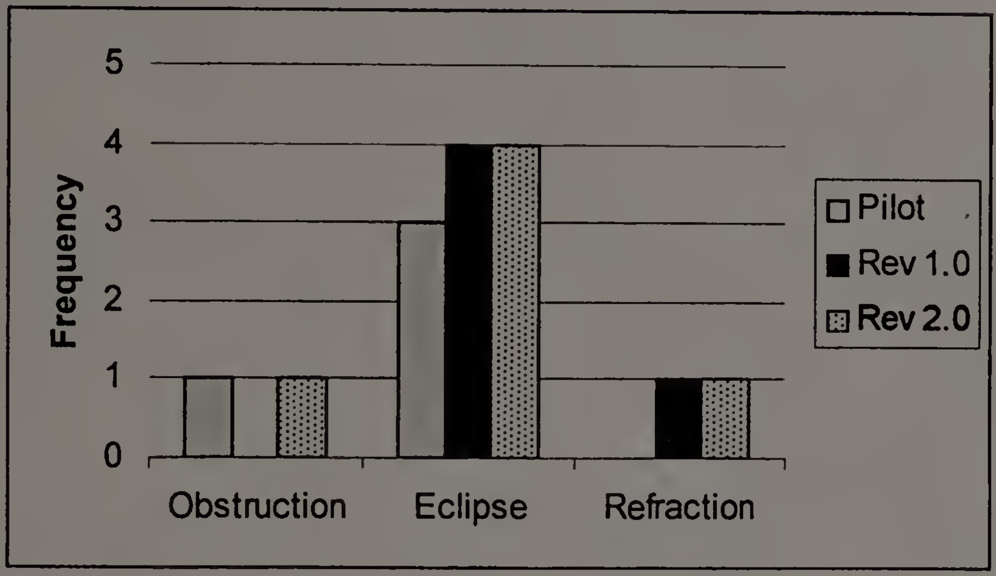


Figure 6.1: Base Theory Frequency Chart

Although a reflection theory was developed by a pilot study student while trying to advance his knowledge of lunar behavior, the four theories can be considered a continuum of cognitive progressions. The obstruction theory with an egocentric perspective is the most explanation simplistic of the four. Although not part of this study, while working with younger children, the researcher observed a greater frequency of learners adhering to this theory. The obstruction theory is the only theory that does not directly identify all stocks required for lunar phases to occur. The theory correctly identifies the Moon but does not include the knowledge domain elements of light (Sun), the Earth, or planetary orbits.

The eclipse theory accounted for 11 initial conceptions. This theory was always drawn and described from a planer perspective above the Earth. This theory correctly identifies all stocks. The learner perspective is always from outer space, yet the observations are from the Earth. Complying with this theory requires the student to disconnect physical observations from cognitive beliefs. With this theory, the student maintains a unicentric view of the planets. The learner does not attempt to describe other perspectives from the Earth, Mars, Sun, or outer space.

The refraction theory is an advancement of the eclipse theory. Two students initially described refraction theories as a result of the realization that an eclipse theory would not allow for linear or predictable lunar behavior. The eclipse theory results in a full Moon for three quarters of the cycle. Two additional students in the pilot study advanced initial eclipse theories to refraction theories when the researcher pointed out the noncontiguous lunar behavior of their explanations. Similar to the eclipse theory, learners maintain a unicentric view of the planets. The obstruction, eclipse, and refraction theories, as described by the learners, are the result of a shadow cast upon the Moon. The refraction theory is the only theory described by learners that enabled light to bend.

The reflection theory was an advancement of an eclipse theory described by one student in the pilot study. The reflection theory was the only incorrect theory that described "reflected" light. The student adhering to this theory believed that lunar phases were caused by light reflecting off the Earth onto the Moon. The inverse of the reflection theory is the closest explanation to the actual causes of observed lunar behavior. The reflection theory maintains a unicentric view of the planets.

There was belief among three pilot study students and three main study students that light could bend. This was either documented in journal entries or microworlds sessions. Later journal entries of the main study learners illustrated light in straight rays. This refuted original beliefs that light could bend. The causes of the cognitive progressions are discussed later in this chapter. All students initially documented light from the Sun as a single ray for each lunar phase example. Later examples illustrated multiple rays emanating from the Sun suggesting a more useful representation of the properties of light.

An outer space perspective from above the Earth was originally maintained by all students in the study. Students gradually documented and discussed alternative views from initial beliefs. Later journal entries would describe perspectives by positioning a person within the view, providing multiple two dimensional views, or attempting to draw three dimensional views.

The researcher was able to document and track student progress in describing lunar phases from phenomenological to more advanced variable dependent explanations. Phenomenological explanations tend to describe observed behaviors using variable independent cause-effect relationships. A phenomenological viewpoint explains concepts using descriptions of formal structures focusing on direct cause-effect relationships. For example, an explanation that the shadow of the earth on the moon creates variational illumination would be considered phenomenological. An inter-relational viewpoint explains concepts involving indirect or triangular cause-effect relationships. Explanations of lunar phenomena that described relationships between the observational perspective, lunar orbit, and sunlight would be an example of inter-relational cognition. The ability to recite analogies or describe alliterative scenarios to support beliefs are other examples of this viewpoint. Students in this study used analogies within other modules, external experiences, or the rocket space flight to support findings.

6.2.1.2 Inability to Disregard Beliefs

The cognitive assessment of learner progressions in this study found that learners tend to tenaciously hold on to initial beliefs (Sadler, 1992; Schoon, 1992). Rather than disregard initial beliefs, four students in this study revised eclipse theor ies to refraction theories to lengthen specific lunar phases. A refraction theory still requires the Earth to cast a shadow upon the Moon similar to the eclipse theory. Two students in the main study, Mark and Cal, continued to document an eclipse theory in post session journals, although during the previous microworld session they clearly stated that the Earth could not cast a shadow on the Moon.

Cal believed that light could bend in some instances although he could not find an example of light bending in the microworld. Joe concluded in an early session that light does not bend, but reverted to this theory later when attempting to explain the nonoccurrence of a lunar eclipse during the full Moon phase. Following a group experiment in the pilot study, students believed that light could not bend as much as they originally thought, even though they could not produce an experiment that supported their case.

6.2.2 Question 2

2. Which features of the microworld bring about conceptual change in learners?

The implementation features of the microworld that bring about conceptual change in learners will be discussed in both global and specific contexts. Conceptual change can generally be attributed to the microworld as a cognitive tool and features specifically that act as a catalyst for cognitive change.

6.2.2.1 The Microworld as a Cognitive Tool

Following an extensive review of microworlds, Perkins and Unger (1994) attributed the conceptual change of learners' representations to three principles. A microworld reduces the cognitive load by minimizing variables and quickly duplicating similar experiments. These representations allow more freedom to inquire in a less cumbersome problem space. Reducing the number of variables allow a learner to clarify cause-effect relationships without attention to extraneous information. A microworld provides immediate results to learner hypotheses. Students can quickly examine similar mental constructions over different scenarios in a short amount of time. Thirdly, a microworld provides effective imagistic analogies that enable students to anchor existing knowledge to target knowledge domains.

Students using the lunar microworld exhibited similar characteristics to those identified by Perkins and Unger (1994). Extensive experimentation was conducted by all students providing immediate feedback. Twenty three different investigations were conducted by main study students exploring 9 similar conjectures. Figure 6.2 illustrates the conjectures investigated per student per session. A typical session would begin with a student exploring (playing with) a module with no specific intent or direction. The student would vocalize a conjecture based upon predictability of observed results or cognitive dissonance, explained later in this section. For example, all but one student in the main study investigated the properties of light. One student, Roberta, concluded through initial explorations that light does not bend, whereas other students were forced to investigate the properties of light when confronted with information that is contrary to their current beliefs. In either case, the microworld was a useful tool for revealing immediate implications for learner hypotheses in a focused problem space.

Student Conjecture Frequency per Session

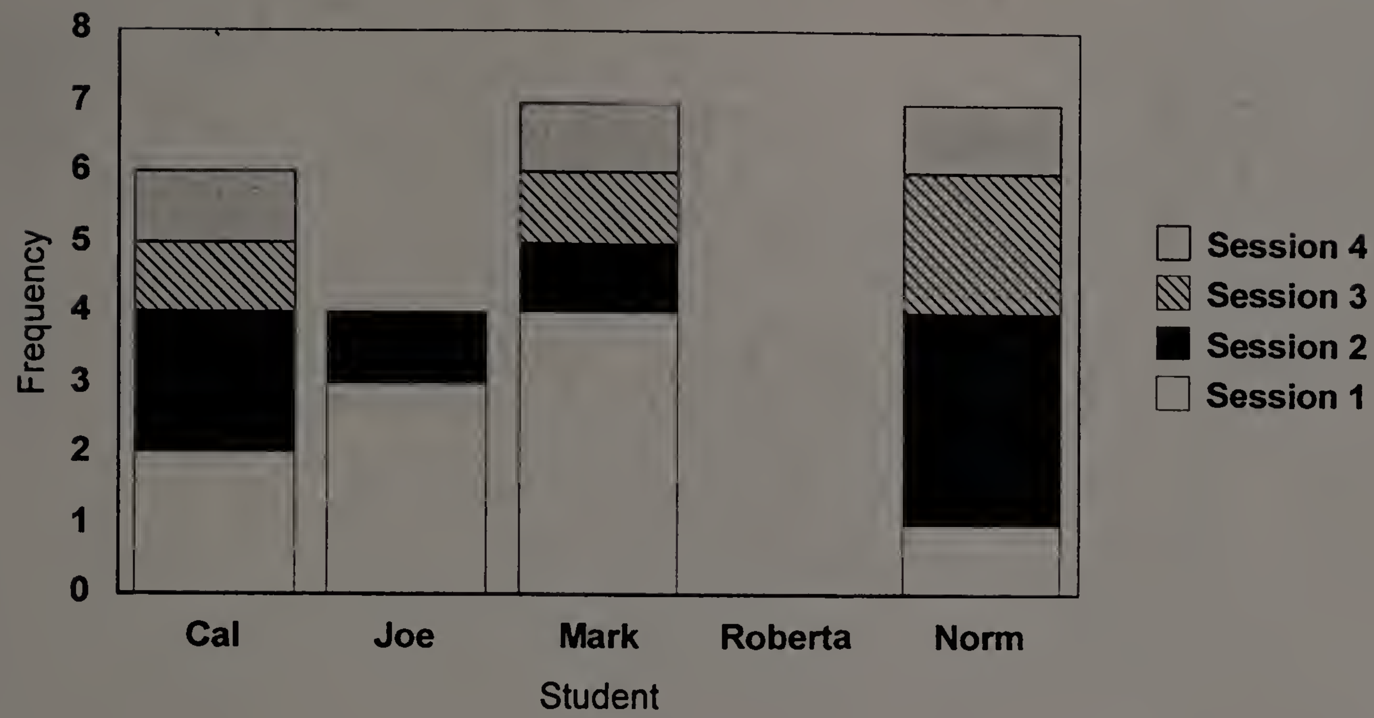


Figure 6.2: Student Conjecture Frequency Per Session

Table 6.1 is a frequency chart of student conjectures for the main study.

Table 6.1: Frequency Chart of Student Conjectures

Conjecture Theme	Frequency
Light refraction properties	******6
One half of the Moon is always bright	*****5
Diagonal orbit angle of moon about the Earth	****4
Time elements associated with lunar phases	**2
Location of Earth perspective effects lunar phases	**2
Tails of the Moon pointing skyward	*1
Amount of Moon illumination changes with the perspective	*1
Planetary surface closest to the Sun is always illuminated	*1
Opposing perspectives create reciprocal lunar views	*1

The first three conjectures comprised 65 percent of all student conjectures. These hypotheses were a direct result of questions raised during exploration or cognitive conflict. For example, Mark had theorized that the Moon was always one half illuminated. He checked the top and side perspectives of the Moon in the views module and compared this to the sphere in the shapes module. This investigation was a result of his direct observations and explorations with the different phases. In a later session, Mark viewed the Moon from the Sun and Mars. The view from the Sun fully illuminated the Moon whereas the view from Mars was completely dark. These observations appeared contrary to Mark's initial conclusion that the Moon was always partially illuminated. The cognitive conflict created by these latter views initiated an additional investigation to accommodate for current theories. In this case, Mark's theory was correct; however, the view appeared to invalidate his theories.

Internal and external analogies were commonly used by students to assimilate existing theories. Internal analogies compared observed phenomena within the microworld. External analogies compared observed phenomena to real world experiences. Students used analogies while exploring or immediately following an inference. The vast majority of analogies were internal and occurred during the investigative or play experiences. Of the 21 analogies made by students in the main group, 12 were internal. The most common internal analogy compared the flashlight, sphere, and eye in the shapes module to the Sun, Moon, and viewing perspective in the phases module. The students would use these comparisons to validate their beliefs. There were many interesting and creative external analogies: All of John's and Norm's analogies were external and represented real world experiences comparing views of the Moon to sunsets, bad lighting, campfires, and light houses. Cal's, Roberta's, and Mark's analogies were all internal to the microworld. For example, they would compare a specific lunar phase within the phases module to a similar scenario within the shapes module to support their beliefs. The researcher suggests that internal-external analogies may be representative of horizontal and vertical learning styles respectively. A horizontal style attempts to make global analogies whereas vertical learning is more focused.

6.2.2.2 Cognitive Conflict

Cognitive conflict occurs when the perceived results of an investigation differ from the expected results, requiring the learner to accommodate for the differences. The accommodation is translated by the student into more intense explorations, conjectures, investigations, and inferences. Table 6.2 is a frequency chart of the cognitive conflicts exhibited by students in this study.

Table 6.2: Frequency Chart of Cognitive Conflicts

Cognitive Conflict	Frequency
Flst surfaces in the X,Z plane could not be viewed	****4
View of the Moon's orbit from Mars and the Sun were not half illuminated	****4
Non-Eclipse of the Moon during a new Moon phase	****4
Sphere and cylinder should look the same in the X,Y view of the shapes module	*1
The tails of a crescent Moon are not horizontal to the Earth	*1
Corners of rooms illuminated in spite of no direct sunlight	*1

The first four conflict items were directly related to features within revision 1.0 of the microworld. The remaining two conflicts were a result of microworld behaviors being compared to real world observations, which was voluntary learning taking place outside the classroom.

The researcher was surprised by the number of students who did not understand fundamental light properties. Four of the five students paused when they could not see the tops of the cylinder or cube in the X,Z view of the shapes module. Two believed that the software was broken or not working properly, providing another example of students wanting to hold on to initial beliefs. Cal concluded that light could bend on curved surface and not on flat surfaces. Following his first session, Joe strongly concluded that light could not bend, yet asked for a very creative design request. He asked for complex shapes that combined flat surfaces with curved surfaces (cube with a sphere on the top, cylinder with a cone on the top). It was if he thought he could "fool" the light into reflecting flat surfaces. In Joe's second session, he concluded that light could not bend and started to use the term "reflected light" in his conversations. Cal eventually concluded that light could not bend.

The views of the Moon from the Sun and from Mars were confusing for three students (one student twice). These learners concluded from their experiences with the shapes module and exploration of the top and side perspectives of the views module that one half an object was always illuminated. The view from the Sun would fully illuminate the Earth and Moon whereas the view from Mars showed no illumination of the objects. An intense investigation usually followed these conflicts where the learners would switch between the view and shapes module to reconcile their confusion. Comparisons would be made between the top view of the shapes module and the top view of the view module. Comparing the side views would be more difficult and required the student to position the flashlight or eye appropriately to create equivalent analogies. The researcher believes that one motivation behind students requesting two perspectives in the shapes module was to help accommodate for the conflict. It is easier to create these perspectives with two eyes. The student does not have to store a mental image of the previous perspective while viewing a new perspective. The last motivation is explained later in this chapter. The last feature that caused disequilibrium in the learners was the non-eclipse of the Moon during the full Moon phase. This should not be a surprise since all students believed in the eclipse theory at one time or another. The views module clearly showed that the Moon revolved in an orbit about the Earth making it impossible to cast any shadows. This orbit was not observed by most learners in the early sessions. Since the lunar orbit in the phases module was an X,Z viewpoint, it is understandable why the students held on to the belief that an eclipse should occur. Similar to the previous incidents of cognitive dissonance, an intense exploration and investigative period would follow. Four of the five students initiated design requests specifically to assist in extended investigations of this conflict.

It was very clear from the interpretation of the data in this study that cognitive dissonance acted as a dual catalyst. It created a disequilibrium that initiated extended investigation by the learner and served as a platform for new design requests that would aid in an explanation.

6.2.3 <u>Question 3</u>

3. Which design features initiated by learners bring about conceptual change?

There were two major design features that brought about conceptual change in learners. The first, an orthogonal view in the phases module, was requested by four students. The second, an additional perspective in the shapes module, was requested by three students. Two other design requests, complex shapes requested by Joe, and multiple earth perspectives, requested by Mark, also acted as a conduit for cognitive transformation.

Three of the five initial session design requests focused on perspective. The learners were not sure what they were looking at, where they were standing, or the positions of the planets. The lunar microworld was, in essence, a two dimensional interface into a three dimensional world. The three perspective requests were cosmetic interface changes and not necessarily a conduit for learning. The fourth initial request, a quiz, was the result of a learner's obsession to obtain the correct answer, and not an agent of change. The last request, complex shapes, was the only initial session design request that resulted in intellectual advancement.

6.2.3.1 Orthogonal View

The orthogonal view in the phases module was independently requested by four different learners (see Figure 5.4 in chapter 5). This design request added an additional view of the Moon orbiting from outer space in frame sequence with the X,Z and X,Y views. It allowed the students to see three simultaneous viewpoints. The orthogonal view was the only view of the three a student could clearly see that the Earth did not cast a shadow on the Moon. Joe, Mark, and Norm all received higher knowledge domain scores following the sessions that used the new design. Each was able to explain lunar behavior in variable dependent terms, citing reflected light, position of the Moon, diagonal orbits, and viewing perspective. Although Roberta requested this feature, she had already scored a maximum score. The post session journals were consistent with the session attributes. The initial design of the study stated that students would not continue sessions after achieving a maximum score. All students requested to continue. In Roberta's case, the researcher asked for design requests that she thought would help other students understand lunar phenomena.

Prior to the orthogonal view in the phases module, visual feedback from the orbit of the Moon about the Earth was only available in the views module. The outer space perspectives in the view module did not provide the same perspective from the Earth in the phases module. Although all perspectives within the view module showed a diagonal orbit, only in the side perspectives (left and right relative to the Sun) was the diagonal orbit evident. In all other perspectives, the orbit of the Moon appeared as an ellipse. Most students noted that the Moon orbited on a diagonal, however, with the exception of Roberta, they did not translate this to a non-eclipse during the full Moon phases. The researcher believes that the students suspected that the Earth could not cast a shadow on the Moon, however, the initial views in the phases module were not conclusive. The students could not mentally sustain a diagonal image in the views module while coordinating a different perspective of the same orbital position of the Moon in the phases module. This design request incorporated a strategic perspective of the view module into an additional perspective within the phases module. This enabled learners to "stand" and view the entire orbit simultaneously from three perspectives.

6.2.3.2 Additional Shapes Perspective

The additional shapes perspective in the shapes module was independently requested by three different learners (see Figure 5.1 in chapter 5). This was the last design request by Norm and Roberta. Both learners fully understood lunar phases but wanted to continue with the project. They felt that this enhancement would help other students understand lunar phases. Both mentioned time in their use of new functionality. Norm stated, "I can freeze time by looking at it from two different views. If I could move the eyes really quick, I could make the phases happen fast. I could have a lot of views at the same time and a lot of phases, but I can only be at one place at a time." Roberta felt that the view assisted learners by providing the ability to be in two places at the same time, and that the position from which one was viewing the Moon causes lunar phases. She felt that this was difficult to understand from a single perspective.

The additional view perspective was the last design enhancement requested by Cal. Remember that Cal was obsessed with providing the correct answer and not with exploring and investigating. When Cal used his quiz at the beginning of the second session, Cal would continually confuse a waning gibbous Moon and a waxing crescent Moon. The two different phases look the same, but are inversely colored, as if a copy of one were flipped horizontally. As discussed in chapter 5, Cal immediately placed the "eyes" and light to simulate these two phases within the shapes module using the sphere. He then compared side perspectives in the views module of the Moon's position in the phases module, concluding that they were opposite. For the first time in the session, Cal made significant progress by stating that it was either where you were standing or the position of the Moon that created phases.

6.2.3.3 <u>Complex Shapes</u>

Following his first session, Joe strongly concluded that light could not bend, yet asked for a very creative design request. He asked for complex shapes that combined flat surfaces with curved surfaces (cube with a sphere on the top, cylinder with a cone on the top). The views clearly showed that complex shapes exhibit the same light characteristics as simple shapes. This enabled Joe to remove the shape from the observed behaviors and focus on the light. This request is similar to the previous requests, although only one perspective is involved. Instead of creating an additional perspective in the same view, two shapes were combined in a single view. These design requests are focused visual analogies that enable students to resolve mental conflicts. Perkins and Unger (1994) refer to a microworld as embodying stripped constructed visual analogs. They are analogs in offering analogical representations of the target domain; constructed in that they are made up for that purpose, rather than borrowed from an existing domain; stripped in that they omit potentially distracting and misleading detail; and visual, harnessing the most powerful of the sensory modalities.

The multiple earth perspectives, requested by Mark, is discussed in the next section.

6.2.4 Question 4

4. How does the learner's ability to pose design features affect conceptual change?

As discussed in the previous section, the ability for learners to pose design features does affect conceptual change by providing focused imagistic analogies as a tool for accommodating cognitive dissonance. The ability to pose design features also affect learning techniques and methodologies.

6.2.4.1 Ownership

Ownership is a definition used by constructionists that refer to learners taking charge of their own learning through the creation of a meaningful artifact. The Revision 2.0 subjects were allowed 45 minutes to explore the microworld following a two week observation of the Moon. Students within this group were not allowed to pose design requests. The students were somewhat mechanical and did not exhibit any behaviors different from the revision 1.0 learners with a few exceptions. Learners in this group did not have any instances of incidental learning and demonstrated less excitement. There was not the sense of ownership that was observed in the revision 1.0 learners.

One of the main tenets of constructionism is that learners actively construct and reconstruct knowledge out of their own experiences in the world (Resnick, 1996). Special emphasis is placed on the construction of knowledge when learners are engaged in building projects. Constructionism is a theory that argues that learners are most likely to become intellectually engaged in independent thinking when they are working on meaningful ventures, whereas constructivism is a theory of learning and defines knowledge acquisition in cognitive terms, constructionism sees an important role for affect. Essentially, the theory is that children (learners) do not absorb ideas, they create ideas and are more likely to create new ideas, theories, and hypotheses when engaged in an external artifact (software design) that has personally meaningful content.

The difference between a constructivist microworld activity such as ThinkerTools (White and Horwitz, 1988) and a constructionist microworld activity such as was used by the session 1.0 students in this study, is ownership. It is the difference between defining a universe or walking through one. If the learner walks through a universe, she can only react to the environment. When a student redefines a universe, she is responsible for the consequences.

Papert (1993), Harel (1992), and Kafai(1996) believe that when children become software designers with individually defined goals, the project has a personally meaningful undertaking capable of mobilizing intellectual energy. The student takes an entirely different approach when compared to completion of daily assigned tasks.

The researcher is not suggesting that microworlds lacking extensive user control cannot promote incidental learning or ownership. It is possible that learners in the 2.0 session did not have time to learn about learning. Only two of the five students were able to fully understand lunar properties within one 45 minute session. The researcher believes that the majority of the students in the revision 2.0 group would have mastered the knowledge domain with an additional session. The researcher is suggesting that the greater the ability for the learner to govern the "world," the greater the potential for learners to take responsibility for their own learning. Incidental learning is characteristic of the learner's ability to take this methodology outside the microworld. In other words, the student is learning to learn.

6.2.4.2 Incidental Learning

All students in the mainstream study exhibited incidences of incidental learning with the exception of Cal.

Joe's discovery of Baily's beads and Mark's exploration of gravity are memorable examples. This discussion cannot duplicate the excitement that Joe felt when he discovered the same phenomenon as a scientist. He had never envisioned himself as "thinking like a scientist." The independent discovery provided Joe with the confidence to continue thinking like a scientist. The demeanor in his sessions changed also as if he were trying to discover new entities. Joe appeared to be learning to learn.

In the first session, Mark had commented that the Moon he observed was pointing up and was different from the one in the microworld. Following the third session, Mark had mastered the basic information necessary to understand lunar phases, but continued to be curious about the difference between observations in the real world versus observations in the microworld. The researcher assisted Mark in creating a model that would aid him in balancing this disequilibrium (illustrated in Figure 5.6 of chapter 5). Originally the camera was situated with the top always pointing true North. To re-create Mark's real world observances, the camera needed to be gravitationally correct with the legs pointing towards the center of the Earth. This new placement resulted in an extensive discussion of gravity. Mark extended his curiosity by theorizing about the view of the Moon from the South pole.

Cal did not have any moments of incidental learning. Not until the last session did Cal begin to take ownership of his own learning. The researcher suggests that microworld based incidental learning is evidence that students are taking charge of their own learning.

6.2.5 <u>Question 5</u>

5. What are the patterns and themes of conceptual change?

Hypotheses 1 through 5 have discussed the patterns and themes of cognitive change in specific terms. Figure 6.3 is a gross level representation of these patterns. The learner began the initial sessions by exploring or playing with each module. During this phase, it was difficult to ascertain whether the students were investigating or exploring. If the learner did not verbalize his or her action, he or she was categorized as playing. It was assumed that investigative learners would be able to verbalize their actions. The majority of play categorizations were seen in the initial sessions. One can consider this as time required for the learner to become familiar with the microworld.

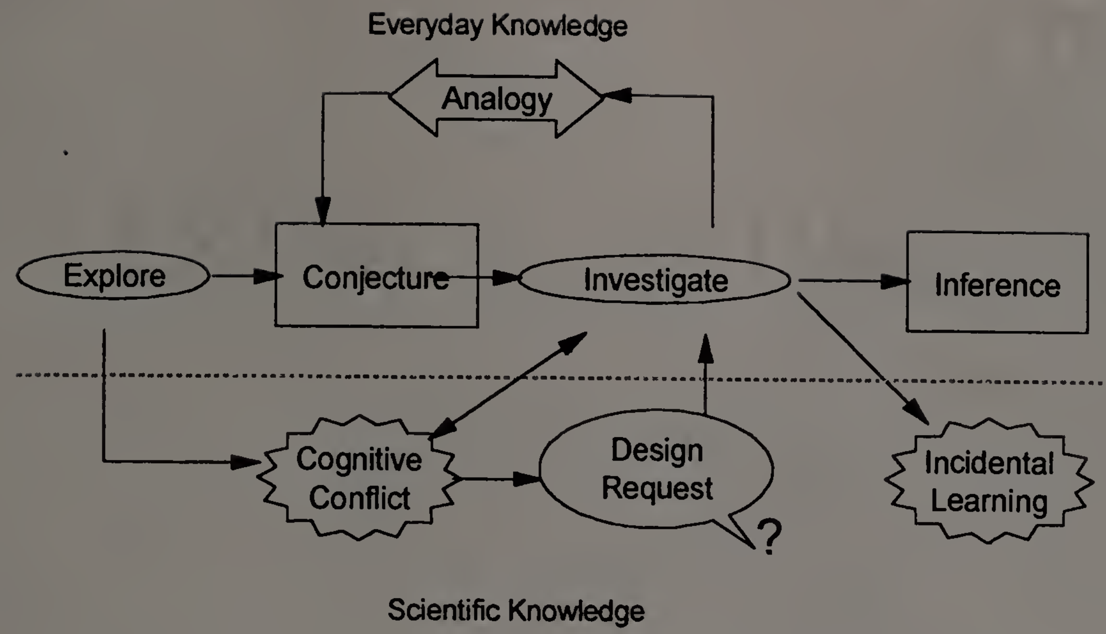


Figure 6.3: Patterns Of Cognitive Change

A conjecture would usually follow an exploration phase. For example, "light does not bend on flat surfaces" or "the Moon is always half bright." The learner would follow a conjecture with a directed investigation. During this investigation, the learner would attempt to make analogies within the microworld or to real world experiences. The investigation would result in an inference or cognitive conflict.

Cognitive conflict was the major catalyst for design requests. Feedback from the design implementations was used to investigate inferences unresolved by the previous state of the microworld. As students gained experience from this meta learning process, they extended the use of this cognitive tool to knowledge domains outside the scope of the microworld including incidental learning.

This model of learning has been described in many different variations. Vygotsky (1978) refers to everyday and scientific knowledge. In Figure 6.2 above processes above the dotted line can be considered everyday knowledge that learners uses to make sense of the world around them. Processes below the dotted line are scientific knowledge that require a mentor to enable more complex knowledge constructs. In this case, the microworld or the researcher could be considered the more abled mentor.

The model could also be representative of assimilation and accommodation. At the heart of constructivism is the idea that learning involves personal constructions of knowledge and is accomplished through the process of equilibration. Assimilation and accommodation are used to operate on the natural tension caused by an individual's need for an organized and ordered world while constantly being confronted to adapt to an ever changing environment (Piaget, 1970).

6.2.6 <u>Question 6</u>

6. Does the computer enhance a constructivist-based activity for exploring lunar phases?

It may become apparent to the reader that a successful constructivist activity was accomplished during the pilot study that did not require the use of a computer. Learners successfully explored lunar phases using a light source and Styrofoam balls on the end of a stick. Learners also successfully experimented with different shaped objects similar to the shapes module in the computerized lunar microworld. Simply "computerizing" an existing activity does not render credibility automatically. Therefore we ask: what learning features and enhancements does computerization bring to the activity other than a different medium? The opposite should also be questioned. Does the computerized microworld activity inhibit learning in any way when compared to real-world activities? These are discussed below.

6.2.6.1 Why Use Computerization

A computerized lunar microworld enables learners to experiment and compare results more quickly, provide simultaneous feedback, provide simulated feedback, and allow individual control unobtainable in real-world experiences. Let us consider Cal's design request to provide two "eye" perspectives in the shapes module. Cal wanted to experiment with "opposite" views. Cal previously compared the side views of the Moon in the views module to the waning gibbous and waxing crescent views in the phases module to a flashlight and sphere in the shapes module. These quick comparisons would be difficult in real world environments and could not be accomplished individually without excessive planning. A microworld must have the ability to provide quick feedback to learners' experiments and hypotheses (Perkins & Unger, 1994).

The microworld provides information that would be extremely difficult using real world experiments. Cal could not stand in two different places at the same time viewing a sphere in a dark room (simultaneous feedback). This is also true with the three learner requests to provide an orthogonal view and an X,Z view of the Moon orbiting the Earth in the phases module. The ability of the microworld to simulate an outer space view of the Moon orbiting the Earth would be difficult to simulate in the classroom. The microworld allowed learners to view the Moon from 9 different perspectives with realistic lighting. Similarly, the rocket ship space travel adventure would also suffer greatly using real world simulations.

A computerized version of the microworld allows for individually paced explorations and learning. Learners can explore questions to the level and detail required. They can create hypotheses and experiments directly related to their needs uninhibited by other students skills, social expertise, or demands. This individualized learning may require less teacher involvement based upon the robustness of the microworld. Imagine if the lunar microworld were robust enough to allow users to create complex shapes for the shapes module, and place camera views anywhere in outer space for the views or phases module. This would remove the researcher from the current study and placed learning entirely in the hands of the student. An adult may be required to train the students in the use of the virtual world or guide students in creating experiments.

6.2.6.2 Why Not Use Computerization

A real world lunar constructivist activity can be less expensive and enable group dynamics that would be difficult to achieve using a computer. Purchasing a computer for all students may be prohibitive where the economics of individualized learning with less instructor involvement does not outweigh initial costs of implementation. The pilot study activity amounted to a few dollars per learner. It would also be difficult to create the same group dynamics using individualized workstations. The pilot study event where two students viewed different phenomena from different perspectives created cognitive dissonance within the entire group. All were interested in who was right and surprised to find out both were correct. Learners learning from learners through grouped dynamics is difficult to simulate on individual workstations. The tactile sensations associated with turning on a flashlight, holding a ball, and twirling a Moon on a stick about your head cannot be simulated on the computer and should not be dismissed as valid qualities of learning.

6.3 Suggestions for Further Research

The current study did not anticipate the extent of learner misconceptions of light. Learners could not quantify fundamental properties of light that would enable them to accurately explain everyday principles. Students believed that light could bend and illuminate dark corners of houses during the day time. They also had difficulty understanding that light reflects differently based upon the shape, color, and contour of surfaces. Light also travels an infinite number of directions in straight paths emanating from the source.

A similar study could be conducted that would allow students to interact in a microworld cube space. The student would have the ability to place different objects in the cube, multiple light sources, and manipulate wall colors and contours. Learner would have the ability to investigate why inside corners of houses appear bright even though there is no direct light source. Through experimentation and investigation, the learners would construct a basic understanding of the properties of light. One variations of this study would have different sized groups of students sharing workstations and experiences. Another variation would have students creating experiments and lessons for other students to learn about light properties. Three dimensional virtual worlds (microworlds) open up a significant new medium for constructivist activities.

Within the space of this study, virtual world functionality has changed significantly. Calagari TrueSpace currently offers a scripting language, Python, that would replace the ToolBook environment. This would enable a researcher to create objects with predefined intelligence. For example, one could create different moons that rotate around a selected planet, or have the ability to glide a light source around a predefined path. This study could be repeated allowing learners to build lunar worlds from a palette of intelligent objects. The current study relied upon the researcher to implement learner design requests. A time period, significantly long, was required to implement these changes. It is probable that learner designed worlds using intelligent objects would more quickly provide feedback resulting in different dynamics and outcomes. Also, there would be a greater sense of ownership for learning. With little effort and expertise, virtual worlds can construct environments to study light properties, geometry, vision, visual perspective, physics, and kinematics. A virtual world, HomeSpace, can be downloaded from Silicon Graphics for free and purchased for less than 100 dollars.

6.4 Implication for Teaching Strategies

Based upon the results of this study the researcher suggests that a constructionist approach to learning lunar phases is not beyond the scope of the typical classroom. This is not to suggest that a teacher would have the time or abilities to implement learner design requests, rather, a combination of classroom activities and virtual world exploration could attain similar results. The following suggestions are not necessarily specific to lunar phases and may be translated to other disciplines.

It is very important to get the students involved in their own learning as soon as possible. Observing lunar phases for two weeks provided enough base information for students to begin developing theories. The instructor should stress the development of the theories and not the attainment of the correct answer. Telling the students that they were early world scientists was an effective ploy in this study. It enabled the students to provide a variety of theories and potentially wrong answers without penalties.

The instructor should stress the process and not the answer. Exercises should be conducted that gather data and provide as many factual observations as possible. This information could be shared in a group setting. Once the data has been gathered, students could individually or as groups create hypotheses that may explain their observations. The teacher should encourage the learners to develop as many relevant hypotheses as possible. Using classroom and computer activities, the students should devise experiments that test the hypotheses.

Once a hypothesis has been investigated, students should strive to define similar situations or observed scientific data that parallel their findings. Incidental learning topics should be kept on a list visible to all. The instructor should not allow the students to develop too many learning threads prior to completing the base investigation.

It is important for the teacher to provide an environment where the student is responsible for a personal artifact. This could be an investigation of a particular theory or new investigation of an incidental learning topic. A student may create a real world artifact that supports the findings, for example, of a true model that correctly represents lunar orbits.

Finally, the teacher should review process and research results with the entire class attributing observations, hypotheses, and conclusions to respective groups or students. The researcher believes that it would be totally appropriate for the class to develop the exam for the project.

6.5 Significance of the Study

This study is significant in that the findings support the results of similar studies, specifically that a lunar microworld can be used to redefine learners concepts of a commonly mistaken phenomena. The lunar microworld is also a gateway example for using virtual world environments as a microworld medium.

The conclusions of this study suggest that when children are personally engaged in their own learning, they not only learn to learn, but become responsible for their own learning. Papert (1993), Harel (1992), and Kafai(1996) believe that when children become software designers with individually defined goals, the project has a personally meaningful undertaking capable of mobilizing intellectual energy. The student takes an entirely different approach when compared to completion of daily assigned tasks.

Student designers participating in this study created 10 different incidental learning threads of investigation.

Rieber (1993) states that learning does not necessarily flow from a fixed sequence of ideas. Using LOGO, mistakes often lead to new discoveries and interesting phenomena causing the learner to abandon initial projects in favor of others that focus on the unexpected results. The syntonic nature of microworlds supports the idea of connected learning, merging new ideas with old to create new knowledge structures.

There is significant evidence in this study to support the use of microworlds as a constructivist activity to overcome learner misperceptions. White and Horwitz (1988) reported that six graders exposed to the ThinkerTools environment significantly outscored a high school control group and a high school group of students that had recently finished a unit on Newtonian mechanics. In a similar study, Wiser and Kipman (1988) found that 100 percent of the participants that used the heat and temperature model were able to provide explicit definitions that differentiated heat and temperature compared to 40% of the non-participants. In a another qualitative study, Dugdale (1992) observed that students using function analyzers demonstrated a greater facility with the relationships between functions, equations, and graphical representations.

The explosion of the technological tools available for educators in the past year has been phenomenal. When this study began, virtual modeling environments and the equipment to support them were economically prohibitive for most educators. Three dimensional virtual worlds can now be downloaded free from the internet and they are capable of execution on inexpensive personal computers. These worlds open up the exploration of physics, kinetics, vision, mathematics, geometry, geology, and environmental studies, just to mention a few. After demonstrating the virtual lunar world to a colleague, it was suggested that his son could use this tool to investigate dinosaur vision classifying carnivores and herbivores by their field of vision. This study is significant in that it successfully used a virtual world as a microworld medium.

APPENDIX A

SAMPLE JOURNAL

Introduction

Over the next four weeks you will be participating in a project that helps a computer scientist to create software that teaches students about "phases of the moon". This will require approximately three hours of classroom time and ten minutes per evening to observe the moon's behavior. You will be participating in a variety activities that include the following:

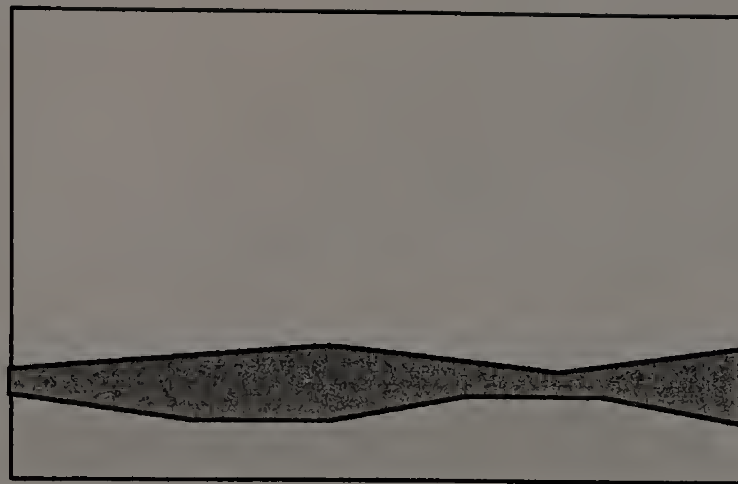
* Exploring MoonRise, a lunar observational model
* Classroom activities that simulate lunar behavior.

The scientist will be interested in all the different ways that students learn about this subject. You will be assisting him in the development of the software by creating a journal of your learning experiences. During the project, the scientist will also interview you with a group of your peers in an effort to incorporate your ideas into the software. You will have multiple opportunities to use the software that you helped design. The scientist will be interested in your feedback about the application and how it could help other students learn about "phases of the moon".

You will be asked to keep a journal that will comprise your observations of the moon, learning experiences, development ideas, and feedback. It is important to understand that there are NO WRONG ANSWERS to the questions and you will not be tested on the subject for a grade. Your teacher will expect you to keep a detailed journal, make the observations of the moon requested by the study, and actively participate in the interviews. Students ideas that are incorporated within the software will be credited throughout the application. The application will become freeware and a copy made available to all participating students.

Week 1

Observe the moon every night for the next week. Record the date and time that you observed the moon. Draw the moon in the boxes provided. Try to be scientific in your drawings paying attention to the size, shape, color, and height in the sky. You may want to observe the moon twice in the same evening. You may also want to observe the moon at different times each night.



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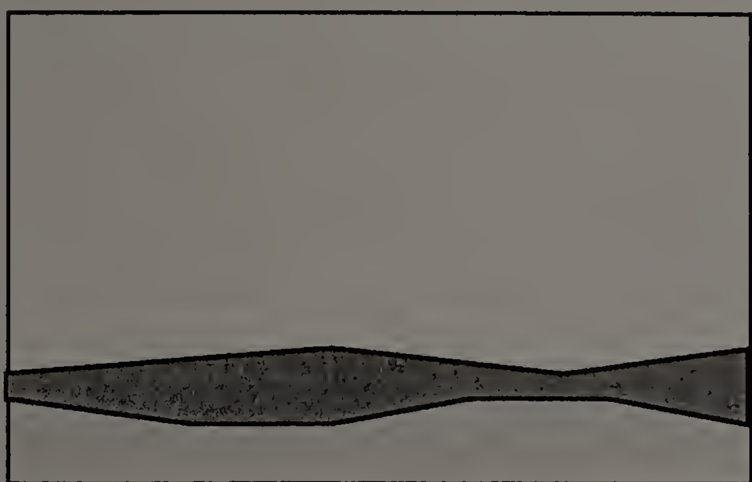

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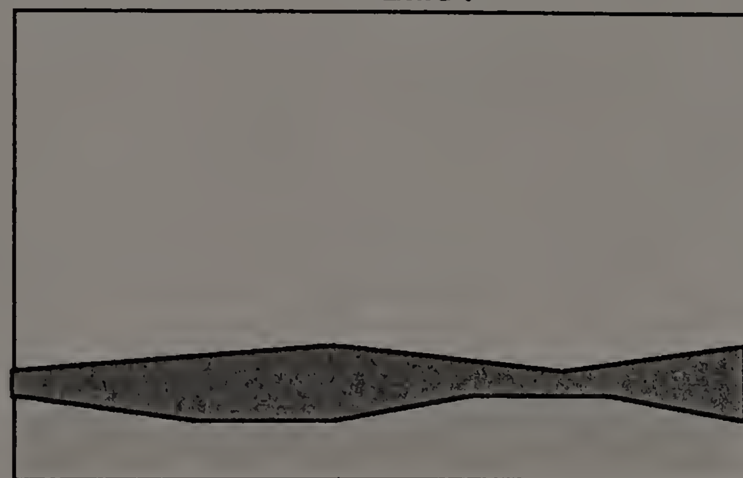

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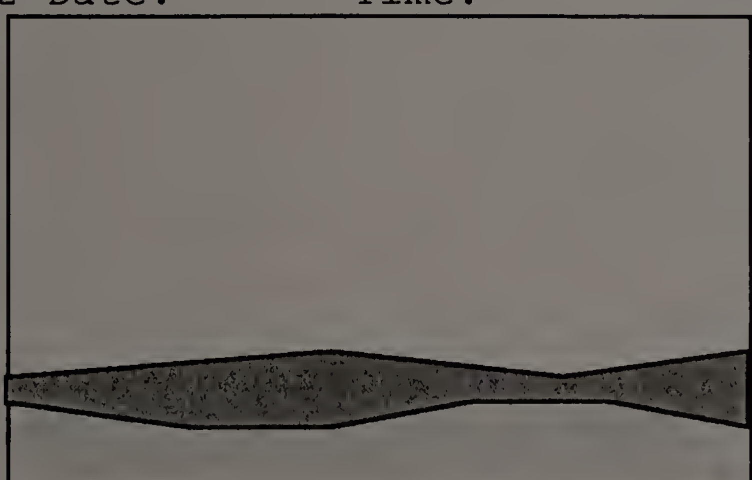

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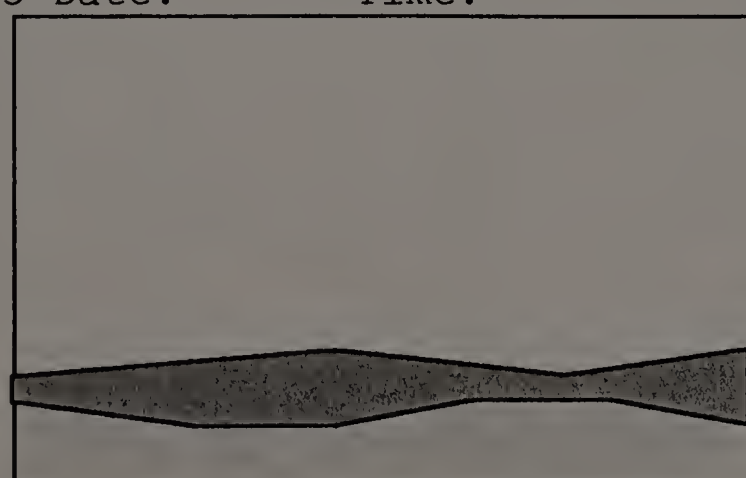

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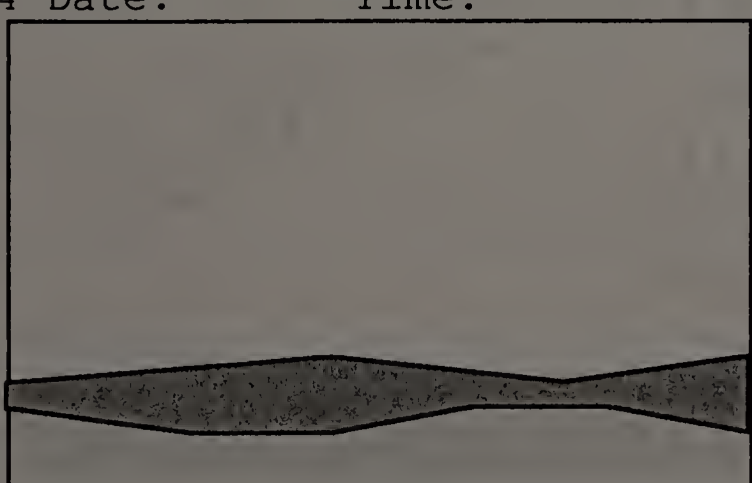

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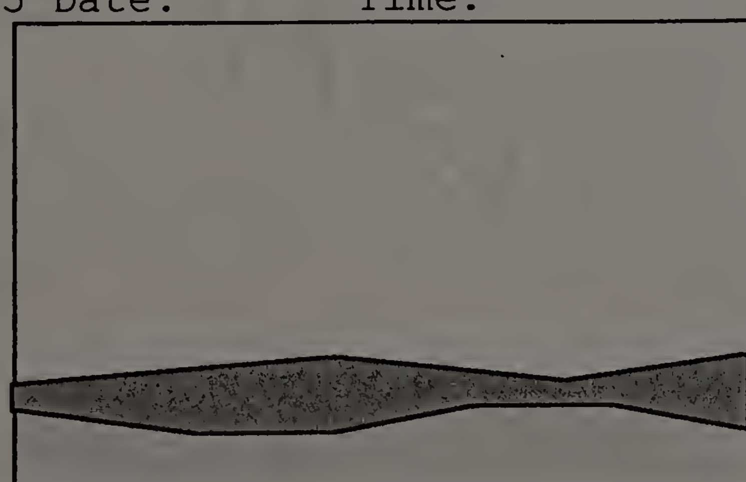

7 Date: Time:

APPENDIX B

CONSENT FORM

A STUDY OF COMPUTER MICROWORLD DEVELOPMENT ADAPTED TO CHILDREN'S CONCEPTIONS

Consent for Voluntary Participation

I volunteer my child to participate in this qualitative study and understand that:

1. She will be interviewed by Russell Couturier on four different occasions while using a computer based microworld. An additional instructor will always be present during the interviews and I may choose to present at all times if requested.

2. The questions she will be answering will address usability of instructional software. I understand that the primary purpose of this research is to identify characteristics of a computer based application that assists learners in comprehending lunar phases.

3. The interview will be digitally recorded via the computer capturing all keystrokes and conversations. At no time will a picture of your child be recorded.

4. Her name will not be used, nor will it be identified personally in any way or at any time. I understand that it will be necessary to identify participants in the dissertation by grade level.

5. I may withdraw my child from part or all of the study at any time.

6. I have the right to review material prior to the final oral exam or other publication.

7. I understand that the results from these interviews will be included in Russell Couturier's doctoral dissertation and may also be included in manuscripts submitted to professional journals for publication.

8. I am free to have my child participate or not to participate without prejudice.

9. Because of the small number of participants, approximately ten, I understand that there is some risk that my child may be identified as a participant in this study.

____________________	__________	____________________	__________
Researcher's Signature	Date	Parent / Guardian Signature	Date

APPENDIX C

TOOLBOOK SCRIPTING LANGUAGE

```
credits page -----------------------------------------------

to handle enterpage

      set visible of button "start" to false

      set item 1 of position of group "blaster" to 10410
      set item 2 of position of group "blaster" to 5220

      set item 1 of position of button "start" to 10370
      set item 2 of position of button "start" to 7170

      set visible of button "start" to true

      step inc from 1 to 450 by 1

            move group "blaster" by 0, -10
            move button "start" by 0, -10

      end

      step inc from 1 to 150 by 1

            move group "blaster" by 0, -20

      end

end
```

```
intro page -----------------------------------------------

to handle changesquares
step inc from 1 to 8
      system `handlex
      system handley
      set square to "item" & inc
      set fillc to item 1 of fillcolor of rectangle square
      if fillc = 240 then
            set item 1 of fillcolor of rectangle square to 0
            set item 2 of fillcolor of rectangle square to 34.43
            set item 3 of fillcolor of rectangle square to 100
      else
            set item 1 of fillcolor of rectangle square to 240
            set item 2 of fillcolor of rectangle square to 50
            set item 3 of fillcolor of rectangle square to 100
      end
end
      handley = floor(handley - 1)
      set item 1 of position of ellipse "throttle" to handlex
      set item 2 of position of ellipse "throttle" to handley

end --end changesquares
to handle sendit
      send countdown
      system handlex
      system handley
step inc from 0 to 382
      mmSeek clip "rocket" to inc wait
      mmShow clip "rocket" in stage "blastoff" wait
      pause 5
      send changesquares
end
      mmSeek clip "rocket" to 1 wait
      mmShow clip "rocket" in stage "blastoff" wait
end --end sendit

to handle leavepage
      mmclose clip "rocket"
end --end leavepage

to handle countdown
step inc from 10 to 0 by -1
      set caption of button "itemdisplay" to inc & ":00:00"
      pause 100
end
end -- enterpage

to handle buttonclick
      go to page "shapes page"
end --buttonclick

to handle mouseenter
      syscursor = 44
end --mouseenter
```

```
to handle mouseleave
      syscursor = default
end --mouseleave

to handle buttonclick
      go to page "orbits page"
end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseleave

to handle buttonclick
      go to page "spacetravel page"
end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end buttonclick

to handle mouseleave
      syscursor = default
end --end mouseleave

to handle buttonclick
      go to page "phases page"
end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseenter

to handle buttonclick
      go to page "exam page"
end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseleave
to handle buttonclick
      send exit
end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter
```

```
to handle mouseleave
      syscursor = default
end --end mouseleave

page shapes -----------------------------------------------

to handle EnterPage

      system radius
      system centerx
      system centery
      system degreelight
      system degreeeye
      system degreeeyered
      system currentclip
      system clipname [3] [7]

      clipname [1] [1] = "spherexz"
      clipname [2] [1] = "spherexy"
      clipname [3] [1] = "spherexyred"
      clipname [1] [2] = "cubexz"
      clipname [2] [2] = "cubexy"
      clipname [3] [2] = "cubexyred"
      clipname [1] [3] = "conexz"
      clipname [2] [3] = "conexy"
      clipname [3] [3] = "conexyred"
      clipname [1] [4] = "cylinderxz"
      clipname [2] [4] = "cylinderxy"
      clipname [3] [4] = "cylinderxyred"
      clipname [1] [5] = "donutxz"
      clipname [2] [5] = "donutxy"
      clipname [3] [5] = "donutxyred"
      clipname [1] [6] = "cubespherexz"
      clipname [2] [6] = "cubespherexy"
      clipname [3] [6] = "cubespherexyred"
      clipname [1] [7] = "cyclonexz"
      clipname [2] [7] = "cyclonexy"
      clipname [3] [7] = "cyclonexyred"

      radius = 2850
      centerx = 8460
      centery = 3240
      degreelight = 90
      degreeeye = 180
      degreeeyered = 270
      currentclip = 1

      mmopen clip clipname [1][1] wait
      mmSeek clip clipname [1][1] to floor((degreelight/3) + .5) wait
      mmShow clip clipname [1][1] in stage "xz" wait

      mmopen clip clipname [2] [1]wait
      mmSeek clip clipname [2] [1] to floor((degreeeye/3) + .5) wait
      mmShow clip clipname [2] [1] in stage "xy" wait
```

```
        mmopen clip clipname [3] [1]wait
        mmSeek clip clipname [3] [1] to floor((degreeeyered/3) + .5) wait
        mmShow clip clipname [3] [1] in stage "xyred" wait

        send moveeye
        send moveeyered
        send movelight

end --enterpage

to handle movelight

        system radius
        system centerx
        system centery
        system degreelight
        system currentclip
        system clipname [3] [7]

        y = (Sin(degreelight * .0174532) * radius) + centery
        x = (Cos(degreelight * .0174532) * radius) + centerx
        move paintobject "lightbulb" to x, y

        mmSeek clip clipname [1][currentclip] to floor((degreelight/3) +
.5) wait
        mmShow clip clipname [1][currentclip] in stage "xz" wait

        send moveview
        send moveviewred

end --movelight

to handle moveeye

        system radius
        system centerx
        system centery
        system degreeeye

        y = (Sin(degreeeye * .0174532) * radius) + centery
        x = (Cos(degreeeye * .0174532) * radius) + centerx
        move paintobject "eye" to x, y

        send moveview

end --end moveeye
```

```
to handle moveeyered

      system radius
      system centerx
      system`centery
      system degreeeyered

      y = (Sin(degreeeyered * .0174532) * radius) + centery
      x = (Cos(degreeeyered * .0174532) * radius) + centerx
      move picture "redeye" to x, y

      send moveviewred

end --end moveeyered

to handle moveview

      system radius
      system centerx
      system centery
      system degreelight
      system degreeeye
      system currentclip
      system clipname [3] [7]

      if degreeeye >= degreelight then
            degreeview = degreeeye - degreelight
      end if

      if degreeeye < degreelight then
            degreeview = 360 - abs(degreeeye - degreelight)
      end if

      mmSeek clip clipname [2][currentclip] to floor((degreeview/3) +
.5) wait
      mmShow clip clipname [2][currentclip] in stage "xy" wait

end --end moveview

to handle moveviewred

      system radius
      system centerx
      system centery
      system degreelight
      system degreeeyered
      system currentclip
      system clipname [3] [7]

      if degreeeyered >= degreelight then
            degreeview = degreeeyered - degreelight
      end if

      if degreeeyered < degreelight then
            degreeview = 360 - abs(degreeeyered - degreelight)
      end if
```

```
      mmSeek clip clipname [3][currentclip] to floor((degreeview/3) +
.5) wait
      mmShow clip clipname [3][currentclip] in stage "xyred" wait

end --end moveviewred


to handle buttonclick
      system currentclip
      system clipname [3] [7]
      mmclose clip clipname [1][currentclip]wait
      mmclose clip clipname [2][currentclip]wait
      mmclose clip clipname [3][currentclip]wait
      currentclip = 1
      mmopen clip clipname [1][currentclip]wait
      mmopen clip clipname [2][currentclip]wait
      mmopen clip clipname [3][currentclip]wait
      send moveview
      send movelight
end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseleave

to handle buttonclick
      system currentclip
      system clipname [3] [7]
      mmclose clip clipname [1][currentclip]wait
      mmclose clip clipname [2][currentclip]wait
      mmclose clip clipname [3][currentclip]wait
      currentclip = 2
      mmopen clip clipname [1][currentclip]wait
      mmopen clip clipname [2][currentclip]wait
      mmopen clip clipname [3][currentclip]wait
      send moveview
      send movelight
end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseleave
```

```
to handle buttonclick
      system currentclip
      system clipname [3] [7]
      mmclose clip clipname [1][currentclip]wait
      mmclose clip clipname [2][currentclip]wait
      mmclose clip clipname [3][currentclip]wait
      currentclip = 3
      mmopen clip clipname [1][currentclip]wait
      mmopen clip clipname [2][currentclip]wait
      mmopen clip clipname [3][currentclip]wait
      send moveview
      send movelight
end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseleave

to handle buttonclick
      system currentclip
      system clipname [3] [7]
      mmclose clip clipname [1][currentclip]wait
      mmclose clip clipname [2][currentclip]wait
      mmclose clip clipname [3][currentclip]wait
      currentclip = 4
      mmopen clip clipname [1][currentclip]wait
      mmopen clip clipname [2][currentclip]wait
      mmopen clip clipname [3][currentclip]wait
      send moveview
      send movelight
end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseleave

to handle buttonclick
      system currentclip
      system clipname [3] [7]
      mmclose clip clipname [1][currentclip]wait
      mmclose clip clipname [2][currentclip]wait
      mmclose clip clipname [3][currentclip]wait
      currentclip = 5
      mmopen clip clipname [1][currentclip]wait
      mmopen clip clipname [2][currentclip]wait
      mmopen clip clipname [3][currentclip]wait
      send moveview
      send movelight
end --end buttonclick
```

```
to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseleave

to handle buttonclick
      system currentclip
      system clipname [3] [7]
      mmclose clip clipname [1][currentclip]wait
      mmclose clip clipname [2][currentclip]wait
      mmclose clip clipname [3][currentclip]wait
      currentclip = 6
      mmopen clip clipname [1][currentclip]wait
      mmopen clip clipname [2][currentclip]wait
      mmopen clip clipname [3][currentclip]wait
      send moveview
      send movelight
end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseleave

to handle buttonclick
      system currentclip
      system clipname [3] [7]
      mmclose clip clipname [1][currentclip]wait
      mmclose clip clipname [2][currentclip]wait
      mmclose clip clipname [3][currentclip]wait
      currentclip = 7
      mmopen clip clipname [1][currentclip]wait
      mmopen clip clipname [2][currentclip]wait
      mmopen clip clipname [3][currentclip]wait
      send moveview
      send movelight
end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseleave
```

```
to handle buttonclick

system radius
system centerx
system centery
system degreeeye

degreeeye = degreeeye - 10

      if degreeeye = 0 then
            degreeeye = 360
      end if

      send moveeye

end --end buttonclick

to handle mouseenter

      syscursor = 44
      caption of statusBar = " Rotates Your View Around the Shape in a
//          Counter-Clockwise Direction"

end --end mouseenter

to handle mouseleave

      syscursor = default
      caption of statusBar = ""

end --end  mouseleave

to handle buttonclick

system radius
system centerx
system centery
system degreeeye

degreeeye = degreeeye + 10

      if degreeeye = 360 then
            degreeeye = 0
      end if

      send moveeye
end --end buttonclick

to handle mouseenter

      syscursor = 44
      caption of statusBar = " Rotates Your View Around the Shape in a
//          Clockwise Direction"

end --end mouseenter
```

```
to handle mouseleave

      syscursor = default
      caption of statusBar = ""

end --end mouseleave

to handle buttonclick

system radius
system centerx
system centery
system degreelight

degreelight = degreelight - 10

      if degreelight = 0 then
            degreelight = 360
      end if

      send movelight

end --end buttonclick

to handle mouseenter

      syscursor = 44
      caption of statusBar = " Rotates the Lightbulb Around the Shape in
a Counter-Clockwise Direction"

end --end mouseenter

to handle mouseleave

      syscursor = default
      caption of statusBar = ""

end --end mouseleave

to handle buttonclick

system radius
system centerx
system centery
system degreelight

      degreelight = degreelight + 10

      if degreelight = 360 then
            degreelight = 0
      end if

      send movelight

end --end buttonclick
```

```
to handle mouseenter

      syscursor = 44
      caption of statusBar = " Rotates the Lightbulb Around the Shape in
a  Clockwise Direction"

end --end mouseenter

to handle mouseleave

      syscursor = default
      caption of statusBar = ""

end --end mouseleave

to handle buttonclick

system radius
system centerx
system centery
system degreeeyered

degreeeyered = degreeeyered - 10

      if degreeeyered = 0 then
            degreeeyered = 360
      end if

      send moveeyered

end --end buttonclick

to handle mouseenter

      syscursor = 44
      caption of statusBar = " Rotates Your View Around the Shape in a
Counter-Clockwise Direction"

end --end mouseenter

to handle mouseleave

      syscursor = default
      caption of statusBar = ""

end --end mouseleave
```

```
to handle buttonclick

system radius
system centerx
system centery
system degreeeyered

degreeeyered = degreeeyered + 10

      if degreeeyered = 360 then
            degreeeyered = 0
      end if

      send moveeyered
end --end buttonclick

to handle mouseenter

      syscursor = 44
      caption of statusBar = " Rotates Your View Around the Shape in a
Clockwise Direction"

end --end mouseenter

to handle mouseleave

      syscursor = default
      caption of statusBar = ""

end --end mouseleave

to handle buttonclick
      go to page "intro page"
end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseleave
```

```
page spacetravel -----------------------------------------------

to handle enterpage

      system.currentview

      mmopen clip "navigate"
      mmopen clip "navigatexy"
      mmopen clip "navigatemoon"
      mmopen clip "ftul"
      mmopen clip "ftsun"
      mmopen clip "fttop"
      mmopen clip "ftvenus"
      mmopen clip "ftleft"
      mmopen clip "ftearth"
      mmopen clip "ftright"
      mmopen clip "ftbot"
      mmopen clip "ftlr"


end --end enterpage


to handle leavepage

      system currentview

      mmclose clip "navigate"
      mmclose clip "navigatexy"
      mmclose clip "navigatemoon"
      mmclose clip "ftul"
      mmclose clip "ftsun"
      mmclose clip "fttop"
      mmclose clip "ftvenus"
      mmclose clip "ftleft"
      mmclose clip "ftearth"
      mmclose clip "ftright"
      mmclose clip "ftbot"
      mmclose clip "ftlr"


end --end leavepage


to handle positionview

system currentview

      mmSeek clip currentview to 0 wait
      mmShow clip currentview in stage "travel" wait

end --end positionview
```

```
to handle buttonclick

      system currentview

      mmPlay clip "navigate" from 1 to 52 in stage "orientation" wait
      mmSeek clip "navigate" to 52 wait
      mmShow clip "navigate" in stage "orientation" wait

      currentview = "ftul"
      send positionview

end --end buttonclick

to handle buttonclick

      system currentview

      mmPlay clip "navigatexy" from 1 to 30 in stage "orientation" wait

      mmSeek clip "navigatexy" to 30 wait
      mmShow clip "navigatexy" in stage "orientation" wait

      currentview = "fttop"
      send positionview

end --end buttonclick


to handle buttonclick

      system currentview

      mmPlay clip "navigate" from 1 to 45 in stage "orientation" wait
      mmSeek clip "navigate" to 45 wait
      mmShow clip "navigate" in stage "orientation" wait

      currentview = "ftvenus"
      send positionview

end --end buttonclick

to handle buttonclick

      system currentview

      mmPlay clip "navigate" from 1 to 60 in stage "orientation" wait
      mmSeek clip "navigate" to 60 wait
      mmShow clip "navigate" in stage "orientation" wait

      currentview = "ftleft"
      send positionview

end  --end buttonclick
```

```
to handle buttonclick

      system currentview

      mmPlay clip "navigatemoon" from 0 to 75 in stage "orientation"
wait
      mmSeek clip "navigatemoon" to 75 wait
      mmShow clip "navigatemoon" in stage "orientation" wait

      currentview = "ftearth"

      send positionview

end --end buttonclick

to handle buttonclick

      system currentview

      mmPlay clip "navigate" from 1 to 30 in stage "orientation" wait
      mmSeek clip "navigate" to 30 wait
      mmShow clip "navigate" in stage "orientation" wait

      currentview = "ftright"
      send positionview

end  --end buttonclick

to handle buttonclick

      system currentview

      mmPlay clip "navigate" from 1 to 15 in stage "orientation" wait
      mmSeek clip "navigate" to 15 wait
      mmShow clip "navigate" in stage "orientation" wait

      currentview = "ftsun"

      send positionview

end --end buttonclick

to handle buttonclick

      system currentview

      mmPlay clip "navigatexy" from 0 to 60 in stage "orientation" wait

      mmSeek clip "navigatexy" to 0 wait
      mmShow clip "navigatexy" in stage "orientation" wait

      currentview = "ftbot"
      send positionview

end --end buttonclick
```

```
to handle buttonclick

	system currentview

	mmPlay clip "navigate" from 1 to 22 in stage "orientation" wait
	mmSeek clip "navigate" to 22 wait
	mmShow clip "navigate" in stage "orientation" wait

	currentview = "ftlr"
	send positionview

end --end buttonclick

to handle buttonclick

	system currentview

	step inc from 0 to 91
		mmSeek clip currentview to inc wait
		mmShow clip currentview in stage "travel" wait
	end

end --end buttonclick

to handle buttonclick
	go to page "intro page"
end --end buttonclick

to handle mouseenter
	syscursor = 44
end --end mouseenter

to handle mouseleave
	syscursor = default
end --end mouseleave
```

```
page orbits ----------------------------------------

to handle enterpage

      system assign

      system previouspage
      system nextpage
      nextpage = "Main"
      previouspage = "Orbits Explanation"

      system moveamount
      system currentday
      system accumday
      system moonpos
      system radius
      system centerx
      system centery
      system sizeearth
      system moonradius
      system moonsize
      system posmovemoon
      system negmovemoon
      system posamount
      system negamount
      system dayfactor
      system worldfactor

      currentday = 1
      accumday = 0
      moveamount = 1
      moonpos = 0
      radius =  2000
      centerx = 6450
      centery = 2900
      sizeearth = 600
      moonradius = 600
      moonsize = 300
      posmovemoon = 12.2
      negmovemoon = -12.2
      posamount = 1.013888888889
      negamount = -1.013888888889
      dayfactor = 1
      worldfactor = 1

      set text of field "moveamount" to 1
      set text of field "display" to 0
      set text of field "lunardisplay" to 0
      set checked of button "daybox" to true
      set checked of button "weekbox" to false
      set checked of button "monthbox" to false
      set text of field "yeardisplay" to 0
      move ellipse "moon" to 8900, 2785
      move ellipse "earth3" to 8150,2635


end  --end enterpage
```

```
to handle buttonclick

system currentday
system moveamount
system accumday
system moonpos
system radius
system centerx
system centery
system sizeearth
system moonradius
system moonsize
system posmovemoon
system negmovemoon
system posamount
system negamount
system dayfactor
system worldfactor

moveamountforward = moveamount * dayfactor

endday = currentday + moveamountforward

if moveamountforward <> 0  and endday >= 0 then

      if endday > currentday then
            inc = posamount
            movemoon = posmovemoon
      else
            inc = negamount
            movemoon = negmovemoon
      end if

      step day from currentday to endday by inc

            y = (Sin(day * .0174532) * radius) + centery
            x = (Cos(day * .0174532) * radius) + centerx
            move ellipse "earth3" to x-sizeearth/2, y-sizeearth/2

            accumday =  accumday + inc
            displayaccumday = accumday
            format displayaccumday as "###"
            set text of field "display" to displayaccumday
            accumyear = floor (accumday / 365.25)
            set text of field "yeardisplay" to accumyear

                  moonpos = moonpos + movemoon
                  if moonpos > 360 then
                        moonpos = movemoon
                  end if

                  lunarm = day / 29.5
                  format lunarm as "###.#"
                  set text of field "lunardisplay" to lunarm
```

```
                        y1 = (Sin(moonpos * .0174532) * moonradius) + y
                        x1 = (Cos(moonpos * .0174532) * moonradius) + x


                        move ellipse "moon" to x1-moonsize/2, y1-moonsize/2


                        if checked of button "rotateearth" then

                              step m from 1 to 16 by worldfactor

                                    show paintobject m of group "world"
                                    pause 2
                                    hide paintobject m of group "world"

                              end
                        end if

                        show paintobject 1 of group "world"
            end step

            currentday = accumday
      end if -- moveamount is 0 days
      end -- end buttonclick

      to handle mouseenter
            syscursor = 44
      end --end mouseenter

      to handle mouseleave
            syscursor = default
      end --end mouseleave

      to handle buttonclick
            system moveamount
            moveamount = moveamount - 1
            set text of field "moveamount" to moveamount
      end --end buttonclick

      to handle mouseenter
            syscursor = 44
      end --end mouseenter

      to handle mouseleave
            syscursor = default
      end --end mouseleave

      to handle buttonclick
            system moveamount
            moveamount = moveamount + 1
            set text of field "moveamount" to moveamount
      end --end buttonclick

      to handle mouseenter
            syscursor = 44
      end --end mouseenter
```

```
to handle mouseleave
      syscursor = default
end --end mouseleave

to handle buttonclick
      go to page "intro page"
end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseleave
```

```
page phases ----------------------------------------

to handle enterpage

	system moonlocation
	system previouslocation
	system currentbutton

	previouslocation = 0
	moonlocation = 0
	currentbutton = 1

	mmopen clip "phaseearth" wait
	mmseek clip "phaseearth" to moonlocation wait
	mmshow clip "phaseearth" in stage "earthview" wait

	mmopen clip "phasemoon" wait
	mmseek clip "phasemoon" to moonlocation wait
	mmshow clip "phasemoon" in stage "moonview" wait

	mmopen clip "phaseem3d" wait
	mmseek clip "phaseem3d" to moonlocation wait
	mmshow clip "phaseem3d" in stage "moonview3d" wait

	send updatedescription
	send cleardescription

end --end enterpage

to handle moveviews

	system moonlocation
	system previouslocation

	if moonlocation > previouslocation then
		stepframe = 1
	else
		stepframe = -1
	end


	step inc from previouslocation to moonlocation by stepframe

		mmseek clip "phaseearth" to inc wait
		mmshow clip "phaseearth" in stage "earthview" wait

		mmseek clip "phasemoon" to inc wait
		mmshow clip "phasemoon" in stage "moonview" wait

		mmseek clip "phaseem3d" to inc wait
		mmshow clip "phaseem3d" in stage "moonview3d" wait

	end --for

	previouslocation = moonlocation

	send updatedays

end --end moveviews
```

```
to handle updatedays

      system moonlocation
      set caption of button day to floor((moonlocation + .5) / 3)

end --end updatedays


to handle updatedescription

system moonlocation
system currentbutton


day = floor((moonlocation + .5) / 3)

conditions
      when day >= 29
            if visible of button "button1" <> true then
                  set visible of button "button1"  to true
                  set visible of button "push1" to true
            end
            currentbutton = 1
      when day >= 0 and day <= 1
            if visible of button "button1" <> true then
                  set visible of button "button1"  to true
                  set visible of button "push1" to true
            end
            currentbutton = 1
      when day >= 2 and day <= 7
            if visible of button "button2" <> true then
                  set visible of button "button2"  to true
                  set visible of button "push2" to true
            end
            currentbutton = 2
      when day >= 8 and day <= 12
            if visible of button "button3" <> true then
                  set visible of button "button3"  to true
                  set visible of button "push3" to true
            end
            currentbutton =3
      when day >= 13 and day <= 16
            if visible of button "button4" <> true then
                  set visible of button "button4"  to true
                  set visible of button "push4" to true
            end
            currentbutton = 4
      when day >= 17 and day <= 22
            if visible of button "button5" <> true then
                  set visible of button "button5"  to true
                  set visible of button "push5" to true
            end
```

```
            currentbutton = 5
      when day >= 23 and day <= 28
            if visible of button "button6" <> true then
                  set visible of button "button6"  to true
            .     set visible of button "push6" to true
            currentbutton =6
            end
end
      send cleardescription
end --end updatedescription

to handle cleardescription

system currentbutton

      step inc from 1 to 6
                  buttonref = "button" & inc
                  if inc <> currentbutton then
                        set visible of button buttonref to false
                        buttonref = "push" & inc
                        set visible of button buttonref to false
                  end

      end
end --end cleardescription

to handle showdescription

            step inc from 1 to 6
                  buttonref = "button" & inc
                  set visible of button buttonref to True
                  buttonref = "push" & inc
                  set visible of button buttonref to True
            end

end --end showdescription

-- move moon left ------------------------------------
to handle buttonclick

system moonlocation
system previouslocation

      moonlocation = moonlocation - 5

            if moonlocation < 0 then
                  moonlocation = 85
                  previouslocation = 90
            end if

      send moveviews

      send updatedescription

end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter
```

```
to handle mouseleave
      syscursor = default
end --end mouseleave

-- move moon right
to handle buttonclick

system moonlocation
system previouslocation

      moonlocation = moonlocation + 5


            if moonlocation > 90 then
                  moonlocation = 5
                  previouslocation = 0
            end if


      send moveviews
      send updatedescription

end --end buttonclick

to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseleave

-- move moon entire cycle ------------------------------------

to handle buttonclick

system moonlocation

step moonlocation from 1 to 90

      mmseek clip "phaseearth" to moonlocation wait
      mmshow clip "phaseearth" in stage "earthview" wait

      mmseek clip "phasemoon" to moonlocation wait
      mmshow clip "phasemoon" in stage "moonview" wait

      mmseek clip "phaseem3d" to moonlocation wait
      mmshow clip "phaseem3d" in stage "moonview3d" wait

      send updatedays
      send updatedescription

end
send showdescription

end --end buttonclick
```

```
to handle mouseenter
      syscursor = 44
end --end mouseenter

to handle mouseleave
      syscursor = default
end --end mouseleave
```

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