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Learning about Phases of the Moon and Eclipses: A Guide for Teachers and Curriculum Developers

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Abstract

National Science Education Standards (1996), published by the National Research Council, recommends that students learn to explain Moon phases and eclipses by the time they graduate from eighth grade. It is clear from the research literature, however, that misconceptions about Moon phases and eclipses are widespread and resistant to change, even among adults. In the most prevalent misconception, children and adults confuse the explanations for phases and eclipses by assuming that lunar phases occur when the Moon enters the Earth's shadow. The good news is that research studies have found approaches based on a constructivist view of learning to be very effective with students in grades five and above. While much research needs to be done, the studies reported here are fruitful in offering ideas for how teachers and curriculum developers can help students achieve the goals outlined in the *National Science Education Standards*.

1. CONTEXT

1.1 Introduction and Overview

Middle school teachers face a major challenge. *National Science Education Standards* (National Research Council 1996) acknowledges research showing that it is difficult for middle school students to understand explanations for Moon phases and eclipses. Yet the Standards go on to say that all students are expected to understand these ideas before they graduate from the eighth grade. These high expectations raise a number of questions for teachers and curriculum developers:

- Are the concepts of Moon phases and eclipses as resistant to change as indicated in the National Science Education Standards?
- At what age level should most students learn to explain the Moon phases and eclipses in terms of a model of the Earth-Moon-Sun system?
- What teaching methods are most effective in helping students acquire a dynamic mental model of the Earth-Moon-Sun system that is consistent with modern science?
- What are the implications of this research for curriculum development and teaching?
- What research remains to be done?

A substantial research base exists to answer these questions. This article summarizes the results of studies in grades 3–12, as well as studies of college students and preservice teachers, using various research methods ranging from quantitative surveys employing questionnaires to qualitative studies based on semistructured interviews. The goal of this research review is to inform teachers and curriculum developers concerning the most effective teaching methods, grade levels, and sequencing of instruction.

To provide insight into the challenges that these concepts pose for students, we begin this review with a brief historical account of how the modern explanatory model of the Earth, Sun, and Moon developed. We present the specific recommendations of the National Science Education Standards and describe how lunar phases and eclipses are typically taught using direct instruction and constructivist-based approaches. In the second section, Literature Review, we summarize the research literature relevant to the above questions. Finally, in the third section, Conclusions and Recommendations, we summarize research results and provide specific recommendations for teachers and curriculum developers.

1.2 Historical Accounts of the Lunar Cycle: Babylon to Copernicus

Unlike the study of most historical events, which are single occurrences, the great advantage of studying the history of astronomy is that we can be sure that ancient people saw the same patterns in the sky that we see today. The most important developments in understanding Moon phases and eclipses occurred in the cities of Babylonia and ancient Greece, culminating in the modern explanation given by Aristotle in his famous treatise *On the Heavens* in the fourth century BC. Although these discoveries occurred quite early, they were hard won and suggestive of the best way to order activities for students.

1.2.1 Babylonia

One of the most remarkable achievements of the ancient world took place in the cities of Babylonia (Toulmin & Goodfield 1961; Neugebaurer 1952). Baked clay tablets inscribed with a written notation called cuneiform provide evidence that over 3,600 years ago, the Babylonians had developed a complex system of mathematics called the *sexagesimal* system, which was based on the number 60. Our own practice of dividing circles into 360 degrees and hours into 60 minutes and 3,600 seconds has roots in this ancient Babylonian system. Significantly, modern astronomy divides the sky into degrees, minutes, and seconds of arc also based on this mathematical system.

Although clay tablets from many centuries have been lost, the existing evidence shows that by the fourth century BC, the Babylonians had applied their number system to making detailed and accurate records of the movement of the Sun, Moon, and planets. By 300 BC, these ancient astronomers recorded the positions of the Sun, Moon, and planets along a complete circle of 360 degrees, divided into 12 divisions, or "signs of the zodiac."

The ancient Babylonian astronomers undoubtedly observed how the relative positions of the Sun and Moon coincided with phases and eclipses. With their sophisticated mathematical system, they were able to create tables of positions that allowed them to predict the times when eclipses of the Moon and the Sun might occur. Although the narrow path of the Moon's shadow across the Earth probably thwarted their ability to predict when a solar eclipse would actually occur at their locality, they would have been quite successful in predicting lunar eclipses (Note 1).

The *Enuma Elish*, a story about the origin of the world dating to the period when these detailed observations were recorded, reveals the Babylonian understanding of the lunar cycle and suggests why detailed observations were made in the first place. In the story, Marduk, the chief god of Babylonia, orders that the world be created and that the Sun and the Moon begin their eternal dance:

He caused the Moon to shine forth; and put the night under her command.
He appointed her to dwell in the night and mark out the time;
Month after month unceasingly he caused her to grow.
At the beginning of the month, as thou risest over the land,
Thou shalt shine for six days;
And with a half disk on the seventh day.
At the full Moon thou shalt stand in opposition to the Sun, in the middle of each month.
When the Sun has overtaken thee on the eastern horizon,
Thou shalt shrink and shape thy crescent backwards.
As invisibility approaches, draw near to the path of the Sun.
And on the twenty-ninth day thou shalt stand in line with the Sun a second time.

To interpret the *Enuma Elish*, it's important to know the details of the monthly lunar cycle. A day or two after the "new Moon," when it is not seen in the sky at all, we first see the Moon as a thin crescent in the evening near the setting Sun. The next night, the Moon appears to be a little higher in the sky at sunset, and the crescent has grown a little wider. Strictly speaking, the angular distance between the Sun and the Moon increases. The Moon's journey in the sky is based upon both the daily rotation of the Earth about its axis and the Moon's motion in orbit about the Earth. As a result, the Moon takes 25 hours to reappear in the same position in the sky. After about a week, the Moon stands at its highest point in the sky at sunset, appearing as a half-illuminated disk with a straight terminator (dividing line between light and dark).

Keeping in mind that the Babylonian month began with the first appearance of the crescent Moon, we can now interpret the following lines:

At the beginning of the month, as thou risest over the land,
Thou shalt shine for six days;
And with half a disk on the seventh day.

Continuing to observe the Moon each evening for one more week, we see it move a little farther away from the Sun each night, until at full Moon, it is seen to be just rising along the eastern horizon as the Sun sets in the west. That observation is noted in the *Enuma Elish* with the following line:

At the full Moon thou shalt stand in opposition to the Sun, in the middle of each month

After full phase, the Moon rises nearly an hour later each night, and the illuminated portion of the Moon that we can see from our vantage point on Earth grows smaller and smaller. If we observe during the early morning hours before sunup, we see the Moon rise first, followed by the Sun. The angular distance between the Sun and Moon continues to shrink each day, as the visible Moon's disk appears to get smaller and smaller, passing the third quarter about a week after the full Moon and becoming a waning crescent as the angular distance between the Sun and Moon continues to decrease. Because these observations are made at sunrise, when the Sun is just rising above the eastern horizon, the crescent faces the opposite way than it did during the first half of the lunar cycle. Finally, the Moon is no longer visible in the daytime or nighttime about 29 days after the previous new Moon, since its crescent is so thin that it cannot be seen at all because of the glare of the Sun. This two-week period after the full Moon is depicted in the following lines from the *Enuma Elish*:

> *When the Sun has overtaken thee on the eastern horizon,*
> *Thou shall shrink and shape thy crescent backwards.*
> *As invisibility approaches, draw near to the path of the Sun.*
> *And on the twenty-ninth day thou shalt stand in line with the Sun a second time.*

Comparing our modern understanding of lunar phases with the *Enuma Elish*, it is obvious that the Babylonians were thoroughly familiar with the cycle of lunar phases. However, we have no evidence that these early Babylonian observers were able to apply or were interested in applying their understanding to explain these phenomena as we would today.

Toulmin & Goodfield (1961) suggested that the Babylonians were motivated to observe and predict the positions of heavenly bodies for religious reasons, since the celestial bodies represented their gods, and by the practical need for a calendar in an agrarian society. They also pointed out that Babylonia was the birthplace of astrology, in which observations and predictions of the positions of the Sun, Moon, and planets provided guidance for the affairs of humankind.

The only record of a mental model held by a Babylonian astronomer of lunar phases (in the modern sense of a physical model to explain why they occur) is from Berossos, a priest of Marduk, who emigrated and lived on the Greek isle of Cos between about 290 and 270 BC. According to Toulmin & Goodfield (1961, 46) Berossos's explanation was as follows:

> *The globe of the Moon is luminous on one hemisphere, the other half being dark blue in colour. When in the course of its journey it comes below the disk of the Sun, the rays of the Sun and its violent heat take hold of it and on account of the properties of light turn the shining half towards that light. But while those upper parts look towards the Sun, the lower part of the Moon, which is not luminous, is indistinguishable from the surrounding atmosphere and so appears dark. When it is quite perpendicular to the rays, all its light is retained on the upper face, and then it is known as the first [or new] Moon.*
>
> *When moving on, the Moon travels toward the eastern parts of the sky, the action of the Sun on it is weakened, and the very edge of its luminous hemisphere casts its splendour on the Earth in the form of a very thin arc, from which it is called the second Moon. Moving round by day, it is called the third Moon, fourth Moon, and so on. On the seventh day, the Sun being in the West, the Moon occupies the middle of the visible sky and, being half-way across from the Sun, turns half of its shining face towards the Earth. But when on the fourteenth day the whole width of the heavens separates the Sun and the Moon, the Moon rising in the East just as the Sun sets in the West, the*

Moon is at that distance free from the effects of the Sun's rays and shows the whole glory of its full sphere as a complete disk.

Because the Babylonian astronomers clearly understood the relationship between the Sun and Moon and the occurrence of Moon phases and eclipses, it seems odd to us that Berossos's mental model did not include a Moon illuminated by the Sun, but rather a moon that provided its own light. It is possible that because the Babylonians considered the Sun and Moon to be gods, they would each provide their own illumination, or that Berossos's ideas did not represent the viewpoint of other Babylonian astronomers. We simply don't know.

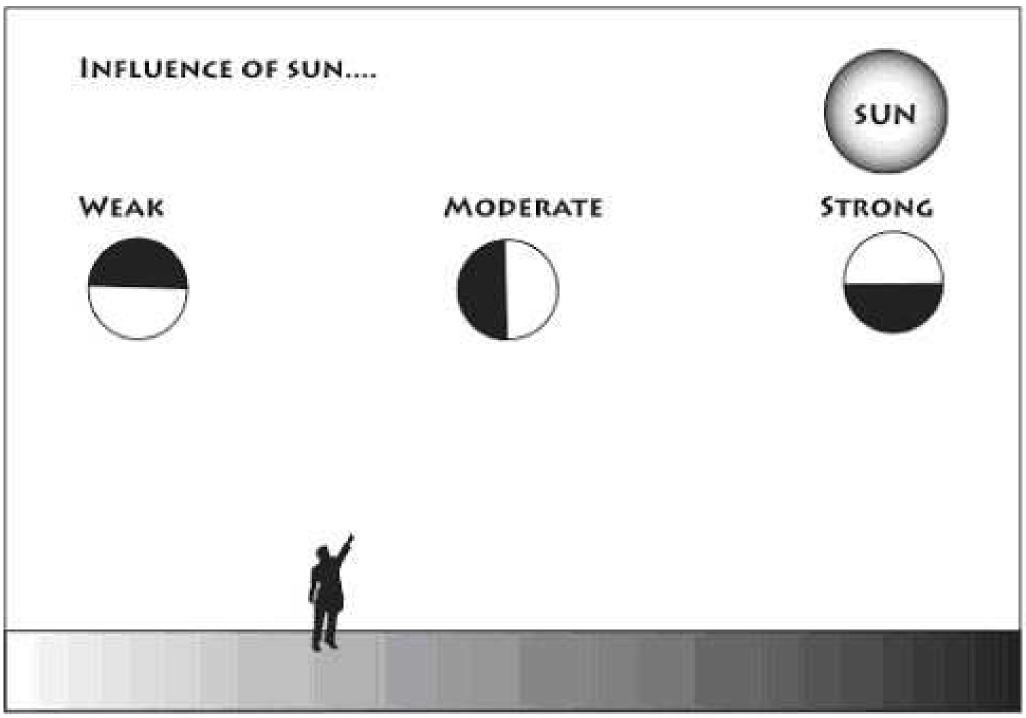

Figure 1. Berossos's Model of Moon Phases (after Toulmin & Goodfield, 1961, page 47).

The mental model put forth by Berossos (illustrated in Figure 1) is oddly similar to certain physical models of the Earth-Moon-Sun system advertised in modern science education catalogues in which the Moon model is actually painted half white and half black to indicate which parts of the Moon are shaded. References to "the dark side of the Moon," meaning the side that always faces away from Earth, are likely to reinforce a misconception that half the Moon is light and half is dark, which would suggest an interpretation of Moon phases that bears some resemblance to Berossos's explanation.

1.2.2 Ancient Greece

Berossos's ideas, based as they were on a flat Earth concept, must have been viewed as quaint by Greek astronomers who progressed much further, not only in understanding the true nature of Moon phases and eclipses, but also in developing the idea of a spherical Earth.

The ideas leading to our current understanding of the Earth-Moon-Sun system originated among natural philosophers of ancient Greece. While we do not have the original records, we do have second- and third-party writings, from a few centuries later, of ideas attributed to the early philosophers. The following are from a compilation of these early writings that show a gradual progression toward Aristotle's full understanding of Moon phases and eclipses (Wheelwright 1960; Dreyer 1953; Toulmin & Goodfield 1961).

The first natural philosopher whose ideas about the cosmos have come down to us through Aristotle's record is Thales of Miletus, who was born in 640 BC and died in 562 BC at the age of 78. Little is known about his astronomical ideas, except that he taught that the Earth floated like a cork in water. According to one account from several centuries later, Thales was able to explain phases and eclipses of the Sun and Moon. However, modern historians discount this report as unlikely in light of other information about Thales and his contemporaries (Dreyer 1953).

Thales's conception of the Earth as a cork floating in water may seem little different from flat-Earth models held by the Babylonians, Egyptians, Chinese, Native Americans, and just about every other culture whose cosmological ideas were passed down from one generation to the next through millennia. Thales's major contribution to the field was a tradition of considering alternative mental models for the Earth among other heavenly bodies.

Sometime after 600 BC, Anaximander of Miletus "held that each of the heavenly bodies is a wheel of fire, surrounded by air, which separates it from the fire at the extremities. The wheel has little breathing holes somewhat like the holes in a flute, and through them the orbs are seen. When the hole of the [solar or lunar] orb gets clogged an eclipse occurs. The Moon goes through its phases as its breathing hole gets successively opened and stopped up" (Wheelwright 1960, 57).

Sometime after 500 BC, Anaxagoras recognized that "it is the Sun that puts brightness into the Moon" (Wheelwright 1960, 164). Regarding the nature of heavenly bodies, Anaxagoras said that "the Sun, Moon and stars are fiery stones bourne about by the revolving movement of the aether. That below the stars there are the Sun, the Moon, and certain invisible bodies that move with them. That the Moon is below the Sun and nearer to the Earth. That the Moon is eclipsed when either the Earth or one of the invisible bodies passes in front of it. That the Moon is composed of Earth and had hills and valleys on it" (172).

Aristotle (384 BC to 322 BC) described a fully consistent model of the Earth-Moon-Sun system in his book, *On the Heavens*. In this book, one of several that have come down to us through various translations, Aristotle justified the conclusion that Earth is a sphere by noting that its shadow on the eclipsed Moon is always curved. In contrast, the Moon's regular phases display a variety of shapes as we see it from various angles as it is illuminated by the Sun. Although the Moon appears half light and half dark with the straight terminator twice every month (at first and third quarter), a straight line between the light and shade is never seen during a lunar eclipse. These ideas are very similar to our modern understanding, except that Aristotle thought Earth was at the center of the Universe, and that the Sun, Moon, and planets all circled around Earth. Like modern scientists, Aristotle gave credit for some of these key ideas to several natural philosophers before him.

Ptolomy's *Almagest* (about 150 AD) represents the culmination of ancient Greek astronomy. It was no less than a full mathematical treatment of Aristotle's mental model of the known components of the Solar System (including the Sun, Moon, Mercury, Mars, Venus, Jupiter, and Saturn). For more than 1,000 years, this book was *the* textbook for anyone who wanted to study astronomy. Bringing together the mathematics achievements of the Babylonians with the logical reasoning of the Greek natural philosophers, this book provided a means for predicting the positions of the Sun, Moon, and planets, and of course, phases and eclipses.

Based as it was on a simplified model of the Earth-Moon-Sun system in which Earth is the largest body in the center, with all other bodies circling Earth's center in perfect circles, Ptolomy's mathematical methods did not work perfectly. Subsequent efforts to modify both the model and mathematical techniques eventually resulted in Copernicus's book, *De Revolutionibus* (On the Revolutions). Published in 1543, the book proposed that the Sun be placed at the center of the Universe, with Earth and the other planets in orbit around the Sun, and the Moon in orbit around Earth.

In summary, the historical record indicates that the first step in developing the modern concept of lunar phases and eclipses was taken by the Babylonians, who were able to discern the cycles of phases and eclipses by systematically observing and recording positions of the Sun and Moon over long periods of time. These early efforts were significantly aided by mathematical methods that continue to be used by modern astronomers. Although they could predict phases and eclipses, it is unlikely that they understood the Earth-Moon-Sun relationship as we do today. The next major step was taken by the ancient Greek natural philosophers when they began a series of conversations lasting several centuries about how best to explain the phenomena of phases and eclipses in terms of mental models. The Greek philosophers frequently justified their mental models in terms of observed phenomena, such as the recognition that the Moon is illuminated by the Sun, and progressing to more subtle inferences, as when Aristotle pointed to the curved shadow on the Moon during a lunar eclipse as evidence that Earth is a sphere. Ancient Greek astronomy culminated in the work of Ptolomy, who transformed Aristotle's model into a mathematical system, thus merging the Babylonian and Greek contributions to science. Ptolomy's *Almagest* led to the work of Copernicus and ultimately to the astronomy of today.

1.3 National Standards and Benchmarks

National Science Education Standards (National Research Council, 1996) recommends that fundamental astronomy concepts be included as an important part of every child's education. Among these are the Earth's spherical shape and gravity (Agan & Sneider 2004), phases of the Moon, and solar and lunar eclipses. Recommendations are also given about the order of activities that should lead to that understanding. Interestingly, these recommendations parallel the development of concepts about the Moon in the history of science. For example, the following recommendations are suggestive of the observations made by the Babylonians:

> By observing the day and night sky regularly, children in grades K–4 will learn to identify sequences of changes and to look for patterns in these changes. As they observe changes, such as the movement of an object's shadow during the course of a day, and the positions of the sun and moon, they will find the patterns in these movements. They can draw the moon's shape for each evening on a

> calendar and then determine the pattern in the shapes over several weeks. These understandings should be confined to observations, descriptions, and finding patterns. Attempting to extend this understanding into explanations using models will be limited by the inability of young children to understand that the earth is approximately spherical. (National Research Council 1996, 154).

In the tradition of the ancient Greeks, teachers of students in upper elementary and middle school (grades five through eight) are told that children of this age are mature enough to explain astronomical phenomena in a way that is consistent with modern science. However, the NSES also offers the following caution:

> The understanding that students gain from their observations in grades K–4 provides the motivation and the basis from which they can begin to construct a model that explains the visual and physical relationships among Earth, Sun, Moon and the solar system . . . Nevertheless, more than half of the students will not be able to use these models to explain the phases of the Moon, and correct explanations for the seasons will be even more difficult to achieve. (National Research Council 1996, 159)

In other words, the NSES tells teachers that it is their job to help all students successfully explain lunar phases and eclipses before they graduate from the eighth grade, despite the anticipated difficulties that more than half of them will encounter.

Benchmarks for Science Literacy (American Association for the Advancement of Science 1993), used by many educators as an alternative set of guidelines for science teaching, makes very similar recommendations but offers some additional insights. *Benchmarks* recommends that by the end of second grade, students learn that "the moon looks a little different each day, but looks the same again about every four weeks" (62). By the end of eighth grade, students should know that "the moon's orbit around the earth once in about 28 days changes what part of the moon is lighted by the sun and how much of that part can be seen from the earth-the phases of the moon" (69). Nonetheless, *Benchmarks* notes that "Moon phases are difficult because of students' unfamiliarity with the geometry of light and 'seeing.' To help figure out the geometry, students can act out the sun-earth-moon relationships and make physical models" (66).

In summary, both *National Science Education Standards* (1996) and *Benchmarks for Science Literacy* (1993) recommend that students become familiar with the lunar cycle of phases in the elementary years, but that explanations of these phenomena in terms of mental models should wait until middle school.

1.4 Instructional Programs

Approximately three centuries elapsed from the time the Babylonians described the lunar cycle to the time that the ancient Greeks were able to provide a satisfactory explanation for lunar phases and eclipses. Given the relative brevity of a human lifespan, we don't have 300 years to enable all children to discover fundamental principles and astronomy independently. We therefore turn to two instructional methods for compressing their learning experience into a much shorter period. Although there are many different ways of teaching about Moon phases and eclipses, most teaching approaches may be categorized as either direct instruction or based on constructivist learning theory.

1.4.1 Direct Instruction

Textbooks generally take a direct instruction approach, presenting information in a straightforward fashion. This approach assumes that students’ initial ideas are either nonexistent or irrelevant to the task of learning new information about science. Hands-on activities are often included for the purpose of demonstrating or confirming information given in the text.

A decade ago, nearly all elementary school textbooks presented Moon phases with brief text and a complex illustration that showed the Earth and two sets of Moon images in eight positions, showing both the "space view" from above the North Pole and the phases of the Moon as they would appear from Earth in each of the eight positions. There have been some improvements in the past few years. Most elementary textbooks now include activities for the primary grades in which children observe the Moon in the sky and create Moon calendars. Older children are invited to hold a ball themselves as they turn it in front of a lamp so that they can see the phases from their own point of view. Textbooks published by Houghton Mifflin, Scott Foresman, and Prentice-Hall since 2000 include these features. However, each of these textbooks also includes the same complex diagrams from the earlier era, and none asks children to observe and record the relative positions of the Sun and Moon in the sky over several weeks, which would allow them to first observe the changes and patterns and then construct an appropriate mental model for explaining these phenomena.

1.4.2 Constructivist Learning

According to constructivist learning theory, individuals construct new concepts by modifying their initial ideas in light of new information. Teaching methods based on constructivist theory therefore take into account students’ initial ideas and provide new information by engaging them in observations of natural phenomena and in discussions with other students. This allows students to unravel any misconceptions that they may have had in order to construct new and more powerful concepts. Constructivist-based activities are generally sequenced so that students clarify and apply their current mental models to new situations and encounter information or ideas that challenge any erroneous beliefs that they may hold. A constructivist approach may be considered a relatively inefficient method of instruction in that it generally takes quite a bit of class time to conduct activities and for students to discuss their own ideas, but it is thought to be more effective than a direct instruction approach in encouraging students to modify their current mental models to accommodate new information or ideas.

Where is the Moon? (Elementary Science Study 1968) was the first widely distributed unit on phases of the Moon and eclipses based on constructivist learning theory. Completed in the late 1960s, the unit involved students in observing and drawing the Sun and Moon in the sky every clear day for a month. Students were shown how to measure the angular distance between the Sun and the Moon in "fists" (one fist is approximately 10 degrees). The teacher’s role in the program was to help students analyze their results and discern the lunar cycle pattern in their data. The students were encouraged to discuss their ideas about Moon phases at various stages and to model phases using a ball and a lamp. The GEMS unit, *Earth, Moon and Stars* (Sneider 1986/1998) and the *Exploring Space: Sun, Moon and Stars* unit in Project Aries (Harvard-Smithsonian Center for Astrophysics 2000) are more recent curriculum guides based on constructivist theory and inspired by the original ESS unit.

For example, in the GEMS unit, during the first two weeks of instruction, students make drawings of the Sun and Moon during the daytime for about two weeks after full Moon. The teacher summarizes the results of the class in a drawing like that shown in Figure 2.

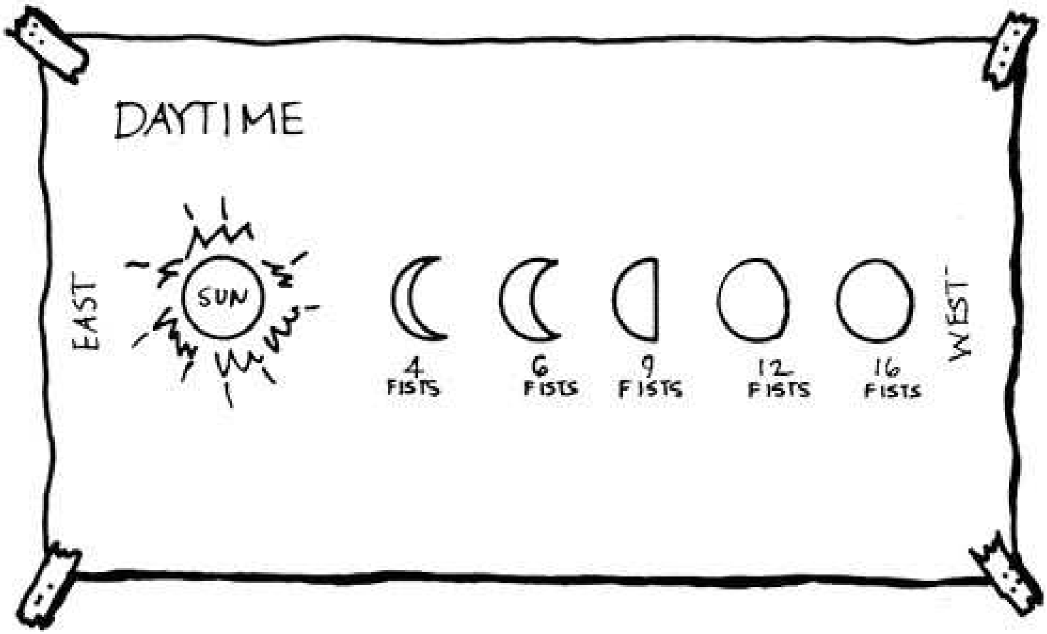

Figure 2. Summary of Students' Daytime Observations after Two Weeks. (From *Earth, Moon, and Stars*, LHS GEMS, page 21).

When the Moon reaches its new phase, where it is so close to the Sun that it cannot be seen at all during the day or night for a few days, the students model Moon phases and eclipses in a darkened room with just one bright light bulb representing the Sun. The students stand in a circle around the light bulb. Each student holds a white ball at arm's length and observes the changing shadow on the ball as he or she slowly turns in place. The ball undergoes phases just like the real Moon in the sky.

Observing Moon phases in this way, from the viewpoint of someone on Earth, clearly illustrates that Moon phases are due to the angular distance between the Sun and the Moon. One half of the Moon is always illuminated. When the Sun and Moon are close together in the sky, the students see only a tiny slice of the illuminated side, so it appears as a crescent. As the angular distance between the Sun and Moon increases, students see more and more of the lit side until they see the entire lit side—the "full Moon." Continuing to turn in place, the students see less and less of the lit side of the Moon until the crescent disappears when the Moon is very close to the Sun.

After this activity, the students are able to predict that in two or three days, the Moon will reappear as a thin crescent in the evening sky near the setting Sun. Many are also able to predict that the Moon will continue to grow "fatter" as it moves farther and farther from the Sun during the subsequent two weeks. They then observe and record the appearance of the Sun and Moon to see if their observations are correct. The students again make drawings, and the teacher summarizes the second half of the lunar cycle, as shown in Figure 3.

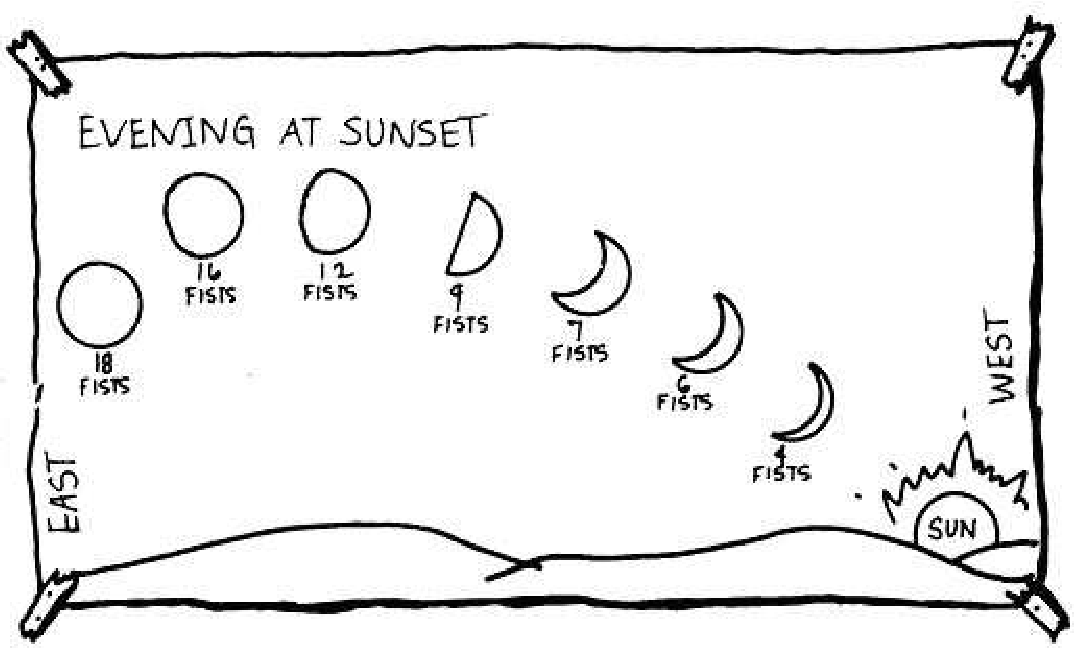

Figure 3. Summary of Students' Evening Observations after Two Weeks (From *Earth, Moon, and Stars*, LHS GEMS, page 22).

The students use the same model to observe eclipses. Lunar eclipses are observed by moving the Moon ball into the shadows cast by their heads, which represent the Earth. A solar eclipse is observed by moving the Moon between the Sun and their eyes. Using this model, the students can easily see that a solar eclipse can only occur when the Moon is in the "new Moon" phase and that a lunar eclipse can only occur when the moon is "full." This activity is illustrated in Figure 4. The authors of this curriculum believe that having students model both phases and eclipses is important for them to be able to clearly distinguish between these two phenomena.

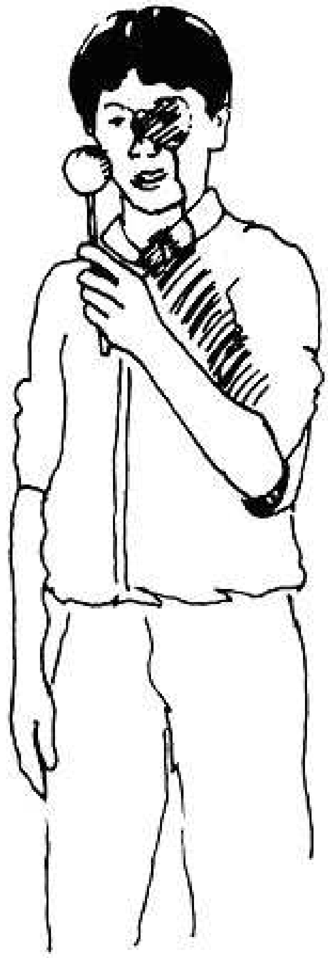

Figure 4. Illustration of How Students See Other Students during Solar Eclipse Modeling Activity (From *Earth, Moon, and Stars*, LHS GEMS, page 28).

In summary, *direct instruction* methods explain lunar phases and eclipses in words, pictures, and confirmatory activities. As a teaching method, it is aimed at communicating information that can easily be assimilated by students. Successful learning depends on students' abilities to memorize and later recall the information. Teaching methods based on *constructivist theory* involve students in observing and recording the Moon's changing position with respect to the Sun and its apparent shape in the sky and using a physical model to reproduce the pattern of lunar phases and eclipses as seen from the Earth viewpoint. As a teaching method, it is aimed at helping students correct possible misconceptions. Successful learning depends on students' abilities to make sense of the data that they collect, to become aware of their current understanding, and if necessary, to change their mental models of the Earth-Moon-Sun system.

It should be kept in mind that actual programs often include complementary components of direct instruction and constructivist activities. Teachers generally give some direct information to students during a constructivist lesson, and students are sometimes able to reconstruct their own thinking when they encounter new information in a textbook that is incompatible with what they previously believed to be true. The challenge for teachers is in choosing the best mixture of direct and constructivist elements for a lesson that will result in effective learning for their students.

2. LITERATURE REVIEW

2.1 Misconceptions that Persist into Adulthood

In his book *Heavenly Errors* (2001), Neil Comins, a professor at the University of Maine, reported that a great many college students held misconceptions about elementary astronomy. Comins defined misconceptions as "any deeply held belief that is inconsistent with currently accepted scientific concepts" (56). For example, he found that many of his college students confuse the explanations for phases and eclipses of the Moon, believing that lunar phases are caused by the shadow of the Earth (Note 2).

One of the most widely known studies regarding students' understandings of various astronomical topics, including the phases of the Moon, was documented in the popular video *A Private Universe* (Schneps 1989). The documentary began with the responses of 23 Harvard University graduates and faculty members to questions about the causes of seasonal change. Upon revealing the surprisingly high percentage of misconceptions among college graduates, the researchers moved to a nearby high school, where the majority of students were found to hold many of the same misconceptions about seasons and phases of the Moon. The video also showed a high school teacher explaining phases of the Moon with the aid of a three-dimensional model of the Sun and direct instruction techniques. The film then documented the teacher's surprise at learning that the lesson was poorly understood.

Heavenly Errors and *A Private Universe* succeed in raising questions about how elementary astronomy concepts are typically presented in modern schools, how student learning is assessed, and how misconceptions can persist into adulthood, including among those who are considered among the most highly educated in our society.

The body of literature that addresses these questions primarily includes studies of students in grades K–12 and studies of preservice teachers and other adult learners. This review of literature is organized according to the instructional audience. We first review studies of elementary, middle, and secondary school students, followed by reviews of studies of preservice teachers and undergraduates. Some of these studies analyzed their subjects' understanding of the phases of the Moon, while other studies explored the effectiveness of instructional methods. We also include a summary of papers that propose novel teaching techniques related to the phases of the Moon but that do not provide evidence of the effectiveness of these methods. Table 1 lists each research study reviewed in this article, while Table 2 lists articles on instructional methods that are insightful but that do not provide research data.

Table 1. Summary of Research on Moon Phases and Eclipses.

Authors & Title (Chronological)	Method & Sample	Results

Jones, B. (1987). Children's Conceptions of the Earth, Sun and Moon.	SAMPLE: 32 students, ages 9-12 METHOD: Semistructured interviews with materials	Classified types of student understandings of S-E-M system, including relative size.
Baxter, J. (1989). Children's Understanding of Familiar Astronomical Events.	SAMPLE: 20 students, ages 9–10, 11–12, 13–14, 15–16 METHOD: Semistructured interviews	Identified five *notions* prevalent in students' understanding of the phases of the Moon.
Dai, M. F. W. (1991). Identification of Misconceptions about the Moon Held by Fifth and Sixth-Graders in Taiwan and an Application of Teaching Strategies for Conceptual Change (Fifth-Graders)	SAMPLE: 800+ Taiwanese students, grades 5 and 6 METHOD: Questionnaire (Identification of Misconceptions about the Moon Test); semistructured interviews; instruction (experimental and control groups)	Found that misconceptions about the phases of the Moon are common. Found experimental instruction to be effective for reducing misconceptions about Moon phases.
Sadler, P. (1992). The Initial Knowledge State of High School Astronomy Students (Science Misconceptions).	SAMPLE: 1,414 high school students METHOD: Questionnaire	Found that misconceptions about astronomical concepts (including the phases of the Moon) are common.
Schoon, K. (1992). Students' Alternative Conceptions of Earth and Space.	SAMPLE: 1,213 participants; 307 grade 7, 340 grade 11, 226 college students, 92 trades people METHOD: Questionnaire	Identified alternative conceptions about the phases of the Moon. Significant differences found only between college students and students grade 5-8.
Callison, P. L., & Wright, E. L. (1993).The Effect of Teaching Strategies Using Models on Pre-Service Elementary Teachers' Conceptions about Earth-Sun-Moon Relationships.	SAMPLE: 76 preservice elementary teachers METHOD: Semistructured interviews; spatial ability and reasoning ability tests	Found the use of physical models to be an effective instructional tool for teaching the concept of the phases of the Moon.

Bisard, W. J., Aron, R. H, Francek, M. A., & Burton, D. N. (1994) Assessing Selected Physical Science and Earth Science Misconceptions of Middle School through University Pre-Service Teachers.	SAMPLE: 708 students: 180 middle school, 157 high school, 371 university students (including 52 science majors in education courses and 27 education majors) METHOD: Questionnaire	Found that misconceptions about astronomical concepts (including the phases of the Moon) are common.
Schoon, K. (1995). The Origin and Extent of Alternative Conceptions in the Earth and Space Sciences: A Survey of Pre-Service Elementary Teachers.	SAMPLE: 122 upper-level elementary education undergraduates METHOD: Questionnaire	Found that many preservice teachers maintain conceptions of the lunar cycle similar to those held by elementary students.
Parker, J., & Heywood, D. (1998). The Earth and Beyond: Developing Primary Teachers' Understanding of Basic Astronomical Events	SAMPLE: 89 British undergraduates (2 groups of preservice and 1 in service group) METHOD: Subjects drew maps demonstrating causal explanations for day/night cycle, seasons, and phases of the Moon.	Documented widespread misconceptions among both preservice and in-service teachers.
Stahly, L., Krockover, G., & Shepardson, D. (1999). Third Grade Students' Ideas about the Lunar Phases.	SAMPLE: 4 students, grade 3 METHOD: Pre- and postinstruction semistructured interviews; instruction	Found experimental instruction to be effective for reducing misconceptions about Moon phases. Considered topic to be appropriate for grades higher than 3.
van Zee, E. (2000). Analysis of Student-Generated Inquiry	SAMPLE: 9 total (6 undergraduate students, 1 graduate student, 2 professors) METHOD: Ethnographic analysis of classroom discussion.	Found that learning in an inquiry-based science classroom could lead to critical examination of previously held beliefs/misconceptions.

Abell, S., Martini, M., & George, M. (2001)."That's What Scientists Have to Do": Preservice Elementary Teachers' Conceptions of Science during a Moon Investigation	SAMPLE: 11 preservice teachers METHOD: Field note observations, semistructured interviews, analysis of Moon journal documents	Found widespread misconceptions related to the lunar cycle.
Abell, S., George, M. & Martini, M. (2002).The Moon Investigation: Instructional Strategies for Elementary Science Methods.	Preservice teachers	Describes a course for teachers in which constructivist theory is used to teach the phases of the Moon. Focus on elementary preservice science education.
Suzuki, M. (2002). Conversations about the Moon with Prospective Teachers in Japan	SAMPLE: 8 Japanese preservice teachers METHOD: Analysis of Moon project documents.	Found that misconceptions of the Moon's phases were common.
Barnett, M. & Morran, J. (2002). Addressing Children's Alternative Frameworks of the Moon's Phases and Eclipses.	SAMPLE: 17 students, grades 5 & 6 METHOD: Observations, interviews, semistructured questionnaires, writing samples; instruction	Identified grade 5 as age appropriate for instruction regarding phases of the Moon.
Dove, J. (2002). Does the Man in the Moon Ever Sleep? An Analysis of Student Answers about Simple Astronomical Events: A Case Study.	SAMPLE: 98 British students, age 12 METHOD: Examination questions	Found that misconceptions about the phases of the Moon are common.
Rider, S. (2002). Perceptions about Moon phases.	SAMPLE: 32 middle school students METHOD: Semistructured interviews	Identified misconceptions about the phases of the Moon.

Trundle, K. C., Atwood, R. K., & Christopher, J. E. (2002). Preservice Elementary Teachers' Conceptions of Moon Phases before and after Instruction.	SAMPLE: 78 preservice elementary teachers METHOD: Pre- and postinstruction semistructured interviews; instruction (experimental and control groups)	Identified alternative conceptions about the phases of the Moon. Found experimental instruction to be effective for reducing alternative conceptions about Moon phases.

Table 2. Instructional Methods: A Summary of Moon Phases and Eclipses

Author & Title (Chronological)	**Instructional Audience**	**Description of Method**
Schatz, D., Fraknoi, A., Robbins, R., & Smith, C. (1978). Effective Astronomy Teaching and Student Reasoning Ability.	Elementary through college students	Workshop guide with activities for teachers of all levels, and extensive readings about applying Piaget's theories to astronomy teaching.
Duckworth, E. (1987). "Observing Moon Phases." In The Having of Wonderful Ideas and Other Essays on Teaching and Learning	Preservice teachers	Preservice teachers were asked to observe the Moon in an exercise designed to teach nature of science.
Schatz, D., & Cooper, D. (1994). Astro Adventures.	Elementary and junior high students	This curriculum resource provides astronomy activities about Moon phases and eclipses (and other topics) and is based on constructivist learning theory.
Nissani, M. (1994). Phases of the Moon.	Elementary students	Activities include direct instruction of the Moon's apparent shape and student observation of the Moon.
Moore, G. R. (1994). Revisiting Science Concepts.	Elementary students	Teaching technique that proposes that students perform Moon observations in multiple elementary grades. Instruction becomes progressively complex as the students' cognitive development matures.
Moore, P. G. (1995). Constructing Understanding of Natural Phenomena.	Elementary students	Describes constructivist activities and teaching techniques for elementary students to learn the phases of the Moon.

Foster, G. (1996). Look to the Moon.	Elementary students	Proposes a method by which the phases of the Moon are modeled in the classroom, using Styrofoam balls, metersticks, and a light bulb.
Chancer, J. & Rester-Zadrow, G. (1997). Moon Journals: Writing, Art and Inquiry through Focused Nature Study.	Elementary students	Strong emphasis on poetry composition and art techniques. Includes instructions for a variety of art projects that include Moon observations.
Brandou, B. (1997). Backyard Astronomy: Observing Moon Phases.	Elementary students	Using constructivist techniques, this article outlines how teachers can assist child-adult pairs in conducting an investigation into the phases of the Moon.

2.2 Teaching and Learning the Phases of the Moon: Elementary School

Stahly, Krockover, and Shepardson (1999) examined third graders' ideas about lunar phases prior to and following instruction designed to promote conceptual change. Their research used the responses of only four students but also provided rich details of the students' responses to semistructured interview questions. Their teacher, who also played a role as a researcher, questioned the students. The interviews included two-dimensional and three-dimensional representations (drawing and models) to explore students' understandings.

Their experimental treatment included six lessons. The first lesson was designed to identify students' conceptions about Moon phases. Subsequent lessons introduced the Moon-Earth-Sun model and asked students to consider the source of moonlight. Finally, the changing relationship among these bodies that results in Moon phases was explored to "review the concepts of how lunar phases occur via the three-dimensional models" (Stahly et al. 1999, 164). Recognizing the spatial reasoning involved in understanding the cause of Moon phases, the instruction was designed "to clarify the translation process of two-dimensional drawings into three-dimensional models" (164).

Posttest results revealed that the instruction was partially effective at addressing students' misconceptions about the phases of the Moon. All the students in the study revealed some scientific conceptions and some alternative conceptions, including inaccurate notions that were resistant to change. So, misconceptions about the phases of the Moon remained, but instruction did result in improvement. Specific positive change in students' responses after instruction included some attention to the relationship between two-dimensional and three-dimensional representations, as "students displayed models and drawings which represent the integration of the Earth's perspective relative to the [three-dimensional] positions of the Sun and Moon" (Stahly et al. 1999, 173). This result may speak to the particular attention that the researchers paid to this problem in the design of the curriculum. In their conclusion, the researchers cautioned that "the topic of lunar phases is a complex concept to master" (174) and recognized that the topic is age-appropriate for students older than the third grade. Nonetheless, Stahly, Krockover, and Shepardson argued that knowledge of students' conceptions about the phases of the Moon would be useful to instruction at any age.

Dai’s doctoral dissertation (1991), conducted in Taiwan, was a thorough study relating fifth and sixth graders’ ideas about the phases of the Moon to instructional methods. Her research identified misconceptions that students held about the Moon and its phases and considered the impact of instruction on these ideas. Her research questions were:

- Can students’ misconceptions be identified by a paper-and-pencil group test?
- To what extent do the fifth and sixth graders possess misconceptions about the Moon? Are there differences attributable to gender, grade, and religious background in the students’ misconceptions?
- Would appropriate teaching materials and effective teaching strategies change misconceptions?

To begin, Dai developed a questionnaire, described as a multiple-choice group assessment instrument, to identify misconceptions about the Moon held by fifth and sixth graders in Taiwan. The Identification of Misconceptions about the Moon Test (IMMT) was developed with a sample of 89 students in two classes. A refined version of the test was administered to an additional 542 students from 12 classes. The validity of the IMMT was confirmed through semistructured interviews and an analysis of distracters in the multiple-choice questions. The interviews offered richer data because the students’ explanations were self-generated and more diverse than those represented on the test. The interviews also served to validate the choice of test questions. The IMMT included questions related to the following topics: the time and direction of moonrise and moonset (the Moon’s daily motion); the monthly phase change of the Moon; phases of the Earth as viewed from the Moon; and models of the Moon-Earth-Sun system to explain the phases of the Moon.

Dai administered the final version of the IMMT to 185 students in four classes, and she used this data to identify misconceptions among her sample, which included a near equal number of boys and girls and fifth and sixth graders, and a mixed sample of students. With this research sample, the IMMT was accompanied by interviews using the same questions. The final results of the test revealed that misconceptions about the Moon are common among fifth and sixth graders in Taiwan. The mean score of the IMMT was 34%, and the mean score from the interview questions was 38%. Specifically, Dai analyzed students’ responses as they relate to certain conceptual categories. These included misconceptions about the time of moonrise; position of the Moon; lunar and Earth phases; and the bird’s-eye view (the model of the Earth-Moon-Sun system). She identified no significant differences between gender, age, or religious background.

Next, Dai tested newly designed instructional methods with an experimental group of two fifth grade classes, while two additional fifth grade classes received traditional textbook instruction. The textbook instruction followed the Taiwanese standard curriculum. Although this revised standard curriculum was based on hands-on science learning, the unit related to the Moon and its phases included only observational activities. In contrast, the experimental treatment used inquiry-based science and hands-on activities. The lesson plan for the experimental treatment included: (1) field observations in which students observed the Moon either at night or in the daytime for several days; (2) the use of models such as the Earth-Moon-Sun model and activities with a volleyball; and (3) a play in which students act out the movements of the sun, the Earth, and the Moon.

The results of a comparison of IMMT scores from experimental and control groups indicated significantly higher scores in posttest results for the experimental groups. Specifically, the gain in scores in the experimental group between preinstruction and postinstruction showed a larger reduction in misconceptions than the gain in scores in the control group. These results supported the interpretation that the new curriculum was more effective at addressing students' misconceptions related to the phases of the Moon. Dai concluded, "misconceptions about the Moon are widely spread among fifth and sixth graders in Taiwan, and . . . the designed teaching materials and strategies are more effective than a text-book centered approach for promoting conceptual change" (104). Specifically, Dai argued, "Students learn concepts through activity rather than through descriptive procedures" (106). At the same time, students in both experimental and control groups continued to hold misconceptions about the Moon and its phases after instruction. The birds's-eye-view concept (the model of the Moon-Earth-Sun system) remained difficult for students after instruction. Dai concluded that "this indicates that this concept is too abstract and far beyond the daily living experiences of elementary pupils" (105). Possible sources for students' misconceptions included inadequate teaching methods, students' cognitive stages (related to spatial and model conceptualization), the influence of folk tales on students' ideas, and the use of ambiguous images and information in textbooks.

A recent study by Barnett and Morran (2002) considered the ideas of 17 fifth-grade students as interpreted through observations, interviews, semi open-ended questionnaires, and samples of students' writing. The research design reflected "the necessity of having multiple means of assessing students' conceptual understanding" (873). Students were interviewed before and after instruction about the phases of the Moon to answer the following questions:

- Can students at the fifth-grade level develop scientifically sophisticated understandings of complex astronomical phenomena, namely the phases of the moon and lunar and solar eclipses?
- Can students' alternative frameworks be ameliorated when exposed to instruction that does not directly address their existing frameworks? (864)

The experimental treatment included class discussions, whole and small group activities, individual activities, and work with three-dimensional dynamic computer models. The entire instructional unit consisted of the following topics:

- The Earth as a sphere and gravity
- Construction of a scale model of the Solar System
- Light reflection and the cause of Moon phases
- The motion of the Earth and the Moon
- The position of the Moon relative to the Earth during its different phases
- The Moon's phases and lunar and solar eclipses

Barnett and Morran (2002) argued that explanations of the two phenomena in the last part of this sequence—phases of the Moon and lunar and solar eclipses—are often confused. Although the instruction they designed did not specifically address any alternative conceptions that students may have held, it was found to be effective. They concluded that "the findings of this study suggest that students at Grade 5 level can develop a sophisticated understanding of the phases of the Moon and eclipses" (875). At the same time, the researchers showed "that instruction does not necessarily need to directly address students' alternative frameworks to promote conceptual change" (875). Barnett and Moran also noted, "Rather than designing instruction that characterizes student alternative frameworks as impediments to conceptual change, science instruction should use students' existing frameworks to scaffold and provide opportunities for students to evaluate and reflect on their evolving understandings as they learn science" (861). The researchers called for a similar study about the phases of the Moon that takes advantage of a larger population of students through the use of a multiple-choice exam in conjunction with random interviews.

Jones, Lynch, and Reesink's 1987 survey of Australian 9–12-year-olds included the use of manipulative objects (polystyrene figures) to enhance their understanding of children's conceptions of the phases of the Moon and the Earth-Moon-Sun system in general. Specifically, their shapes included two-dimensional and three-dimensional objects of various sizes. Students were then able to select representational pieces that mimic the Moon as it appears either from Earth or from space. Students were also able to choose objects of different sizes to represent the relative differences between the Sun, Earth, and Moon. The semistructured interview they conducted included asking the students to explain (with the use of the objects) the causal relationship involved in the phases of the Moon. They classified the results into five general categories that evolved from a magical description of the system to the generally accepted scientific description of the system. The implications for teaching from this study included a focus on the child's emergent developmental ability and his or her understanding of astronomical models. They also concluded that the subject's ability to understand scientific knowledge and models is interconnected with other areas of learning. Their research experience led them to conclude that constructivist methods are of great value for teaching and learning the phases of the Moon.

Taken together, these studies support the conclusion that although students in grades three through six initially hold a great many misconceptions about Moon phases and eclipses, instruction that involves students in observing the sky and in using three-dimensional models can be effective in significantly improving student understanding. In addition, research indicated that third grade is too early for effectively teaching these concepts. Instruction is unlikely to be effective for most students until grades five or six.

The following summaries describe teaching techniques proposed for classroom projects involving Moon study. They do not document evidence of learning, but they offer ideas for teaching practices.

Hickman (1993) proposed a teaching technique that she referred to as a "moon dance" to assist younger learners with the phases of the Moon. Students held a Styrofoam ball in front of a light source and used different arm positions to mimic the phases of the Moon. In this technique, the student's head was considered to be the Earth so that the confusion often associated with a "space-based" perspective could be avoided.

G. R. Moore's 1994 paper proposed a spiraling construct in science education related to learning the phases of the Moon. Students in grades one and two observed Moon phases and tracked the changes. This initial effort was followed up in subsequent years with more advanced conceptual tasks and science activities in which modeling the Earth-Moon-Sun system became increasingly abstract. In this model, the students' increasing ability to master sophisticated mental models was matched with curriculum to address learning lunar phases.

P. G. Moore (1995) described a curriculum for second graders' yearlong observations of the Moon based on constructivist learning theory. Students compiled an ongoing moon calendar by adding daily "tickets" to a posted monthly outline. Discussion of the Moon and its phases occurred after two months of data collection. The authors noted, "It is important to note that although second-grade students are not developmentally ready to fully understand the reasons for the patterns, they can see, through the collected data, that the patterns and changes occur regularly" (14).

Foster (1996) developed a tool for modeling the Earth-Moon-Sun system for elementary students using simple materials. The students observed the Moon (Styrofoam ball) at the end of a meter stick and replicated the phases of the Moon by observing the shadows formed when light in the room was restricted to a central light source (an unshaded light bulb held aloft by the teacher.) In his proposed method, the student's head became the Earth, and the shaded part of the Moon model was presented from an Earth-based perspective.

Brandou (1997) proposed an extended investigation of the phases of the Moon as a means of getting families interested in astronomy. This article described how teachers assisted student-adult pairs with a Moon investigation that was principally conducted as an extended homework assignment. "Teachers should encourage adults to engage children in constructing knowledge by asking questions based on their own observations. The adults should begin with questions that elicit descriptions, explanations, predictions, and the testing of tentative ideas" (19). Brandou provided a list of example questions for each of these kinds of mental tasks related to learning the phases of the Moon and developed techniques that would help adults encourage children to build theories as a means of fostering their lifelong interest in astronomy.

Joni Chancer and Gina Rester-Zodrow's 1997 book, *Moon Journals: Writing, Art, and Inquiry Through Focused Nature Study*, contains writing and art exercises for primary school students. The text documented Chancer's fourth graders as they completed the projects and included examples of their artwork and poems. The writing activities described use of metaphorical writing, presenting observations in different poetic forms, and the use of memoir writing, among others. Art activities were likewise rich in illustrative detail and included a survey of techniques and media. The final chapter in this text encouraged teachers to keep a Moon journal of their own. Their methods are particularly useful for classroom instructors who want to connect science learning with literacy outcomes, and for art teachers who want to bring science content or nature study into their classrooms.

2.3 Teaching and Learning the Phases of the Moon: Middle and High School

Dove (2002) used a small and homogeneous sample: 98 twelve-year-old English schoolgirls who completed their exams at end of term. These students received instruction concerning various astronomical topics, including phases of the Moon. This instruction was largely a textbook-based curriculum and lecture, but also included simulations of the Moon phases with the use of globes, lights, and tennis balls. The exam questions required that the students use their knowledge of Moon phases in various situations. For example, the students were asked to consider the "period of Earth days from Sunrise to Sunrise on the Moon" (825). The students were also questioned about the "dark side of the Moon" (a misnomer, as all sides of the Moon receive sunlight at some point during the Moon's orbit around the Earth). The results of this study indicated the high prevalence of misconceptions, as only 40% of the students correctly answered questions about the "dark side of the Moon," and only 35% of the students correctly answered questions about the length of daylight on the Moon. Dove interpreted these results as critical of a textbook-centered curriculum, pointing out that many textbooks use ambiguous two-dimensional images of the Earth-Moon-Sun system to represent three-dimensional models. This ambiguity of models and images leads to difficulties when students are asked to change perspectives. Dove indicated in this study that many astronomical terms are misleading, citing the term *quarter Moon*, which signifies that half of the Moon is lit up as viewed from Earth. Dove's recommendations include activity-based instruction to help overcome the curricular obstacles.

During his work as a middle school teacher, Rider (2002) carried out semistructured interviews with 32 of his students who had not received any recent instruction on the topic of the Moon’s phases. His paper, "Perceptions about Moon Phases," summarized common ideas held by these students as they related to general knowledge about Moon phases and three-dimensional modeling of the phases. He concluded, "While students have bits and pieces of correct information, very few correctly understand the concepts behind Moon phases" (50). From this quick summary, Rider recommended a constructivist approach to instruction for the topic. "The important thing is to provide as many different types of activities as possible and to allow students a chance to reflect on what they have observed and to compare their evidence with their original concepts" (51). The educator claimed that student learning about the phases of the Moon could be enhanced through activities that allow for self-reflection.

Baxter (1989) administered interviews about astronomical phenomena, including phases of the Moon, to 20 students aged 9 to 16. Baxter’s interview sample included five groups of students in specific age groups: 9–10 years old, 11–12 years old, 13–14 years old, and 15–16 years old. Baxter’s sample of students included an equal number of girls and boys. An analysis of results revealed the prevalence of five notions common to students’ understanding about the phases of the Moon. These included:

Notion 1. Clouds cover the part of the Moon that we cannot see.

Notion 2. Planets cast shadows on the part of the Moon that we cannot see.

Notion 3. The shadow of the Sun falls on the Moon, blocking our view of it.

Notion 4. The shadow of the Earth falls on the Moon, blocking our view of it.

Notion 5. A portion of the illuminated side of the Moon is visible from Earth.

Notion 5 is the modern scientific model for lunar phases. This study helped define common ideas that students held about the cause of the phases of the Moon and showed the prevalence of misconceptions. The study’s participants most commonly held Notion 4 at all ages. In fact, students ages 13–16 held either Notion 4 or 5, though the majority subscribed to Notion 4.

Phillip Sadler, the primary researcher involved in creating the *Private Universe* video, completed a research study for his doctoral dissertation (1992) that investigated 1,414 high school earth science and astronomy students’ responses to a general astronomy questionnaire. Like the work reported above, he found that most students held misconceptions about astronomical phenomena, including phases of the Moon. The mean number of correct answers was only 34%. Sadler’s research considered the impact of schooling and demographics on the test results, and he later analyzed the effect of different distracters on the responses to the multiple-choice questions (1996). He found that as students matured and learned more about a particular topic, their preference for certain incorrect explanations increased. When these distracters were present, the number of incorrect answers to the question actually increased as students started to learn about the topic. Sadler argued that even though these responses were incorrect, they represented a more sophisticated understanding of the phenomenon. In other words, students’ mistakes can be an important part of the learning process.

Schoon (1992) administered a questionnaire to 1,213 participants in a cross-age study that included 307 seventh graders, 340 11th graders, 226 college students, and 92 tradespeople. Overall, Schoon found that "the holding of alternative conceptions in the Earth and space sciences was widespread" (213). Like Sadler, Schoon also analyzed which distracters were selected. Alternative concepts were labeled as primary ("chosen more often than scientifically acceptable conceptions"), secondary ("chosen less often than scientifically acceptable conceptions"), and functional ("could interfere with one's ability to function in society"). He also analyzed results by gender, race/ethnicity, educational experience, and geographic location. Schoon found significant difference "only between the college level and the fifth and eighth grades" (213). Among the respondents, "students who have taken Earth science classes subscribed to slightly fewer alternative conceptions than those who have not" (213). Additionally, Schoon's questionnaire identified primary alternative conceptions that are relevant to students' understanding of the phases of the Moon:

- "When we have a full Moon, people on the same night in Australia have a different phase of the Moon." (52.9 % of total respondents gave this incorrect response.)
- "The different phases of the Moon are caused by the shadow of Earth falling on the Moon." (48.1% incorrect)

Secondary alternative conceptions were related to the period of the Moon's orbit and the source of Moonlight. Schoon's recommendations for astronomy instruction called for the use of direct observations, classroom discussions, and a review of the history of the scientific topic. He argued that students must be aware of the alternative conceptions that they hold, concluding, "For many students, the manipulation of physical materials, as well as the discoveries they made for themselves, help the retention of information" (214).

2.4 Teaching and Learning the Phases of the Moon: Adult Learners

Researchers in astronomy education have also considered adults' understandings about the phases of the Moon. Callison and Wright (1993) tested an instructional method that emphasized the use of models of the Earth-Moon-Sun system with a group of preservice elementary teachers. The researchers divided their group of 76 participants into four sections and administered the experimental instruction to three sections. Before instruction, all participants were interviewed regarding their prior knowledge of the subject and completed tests to assess their spatial and reasoning ability.

The Callison and Wright study identified a majority of preservice teachers in their sample with misconceptions about the phases of the Moon. However, the experimental instructional method significantly impacted the three experimental groups. The control group, which received instruction about the Moon's phases without the help of models, did not improve their results. The participants' scores on spatial and reasoning tests did not significantly relate to their improvement in understanding the phases of the Moon after instruction. The researchers concluded that the use of physical models when teaching the phases of the Moon can significantly improve instruction.

Bisard and colleagues (1994) conducted a cross-age study using a general science questionnaire. The study's sample included 708 participants ranging from middle school students to university students. This latter population consisted of students with a strong science background, and a small sample of preservice teachers. The results of the study showed a large number of misconceptions among all participants with regard to astronomical concepts, including a score of 39.2% for the question related to the phases of the

Moon. The researchers found test scores to be positively correlated with age, except for the preservice general elementary teachers, whose scores were dramatically lower than others of their age. This group of future teachers scored just above then-middle school students' results. The authors expressed significant concern with these findings: "This suggests that future general elementary teachers seem to have about as many misconceptions concerning the topics covered in this survey as do typical middle school students" (40).

Schoon's 1995 study of 122 preservice teachers in the American Midwest and their conceptions of the Moon phases used a questionnaire and found that many held the same misconceptions as primary school students. Among his findings, he reported that 62.3% of his survey respondents believed that the phases of the Moon are caused by the Earth's shadow. When subjects were asked about the origin of their misconceptions, Schoon reported that four common sources for erroneous beliefs about the nature of lunar phases included school science lessons, "logical" figuring of the solution, the media, and folklore.

Parker and Heywood (1998) focused on the British education system. Their survey included three groups: two sections of preservice teachers and a small third group of in-service teachers. They asked their sample groups to use a blank piece of paper to map and demonstrate the causal relationships within the Earth-Moon-Sun system to produce the observed phases of the Moon via annotated drawings. These drawings were then categorized according to common schema and were developed into six categories of response. They found that misconceptions regarding the Moon's phases were both common and similar to misconceptions widely held by students.

A recent study by Trundle, Atwood, and Christopher (2002) provided important details for understanding preservice teachers' knowledge about the phases of the Moon. The research questions that guided the study were:

- Before instruction, what are the types of conceptual understandings held by elementary preservice teachers about the cause of the Moon phases?
- How do elementary preservice teachers' conceptual understandings of Moon phases differ after completion of instruction on this topic?
- On the cause of Moon phases, how do the conceptual understandings of elementary preservice teachers who completed the instruction compare to those who did not?
- Does using a three-dimensional model or making a two-dimensional drawing during pre- instruction interviews have instructional value? (636)

Subjects of the study were 78 preservice elementary teachers enrolled in an undergraduate science education course. The subjects were divided into four groups. Three groups received the experimental treatment. Two of the experimental groups were administered pre- and post instruction interviews. The third group received only postinstruction interviews. The fourth group received textbook-based instruction and postinstruction interviews. The experimental treatment was based on Lillian McDermott's *Physics by Inquiry*, a highly regarded and well-researched curriculum based on constructivist learning theory. The experimental treatment used students' observations, group discussion, and the creation of physical models.

Participants' responses to the semistructured interviews were coded with respect to their scientific understanding of the phases of the Moon. Preinstruction interviews revealed a large number of alternative conceptions about the phases of the Moon. Postinstruction interviews supported the conclusion that "after instruction, most participants showed evidence of holding a scientific conception or of showing more scientific fragments of understanding than they had shown before instruction" (Trundle et al. 2002, 653). Furthermore, preservice teachers in the experimental groups held fewer misconceptions about the Moon's phases after instruction than did those in the control group. Finally, the use of models in the preinstruction interviews did not seem to affect the outcome. The inferences that can be drawn from this study are very strong given the rigorous experimental design employed by the researchers.

The following summaries describe techniques for teaching adults about Moon phases and eclipses, but do not provide evidence of educational effectiveness.

It is difficult to say for certain who first introduced methods for teaching about Moon phases and eclipses based on constructivist learning theory. It is certain, however, that one of the most influential educators who pioneered the application of Piaget's theories to astronomy teaching has been Dennis Schatz. His astronomy teacher's workshop guide, with coauthors Fraknoi, Robbins, and Smith (1978), presented an activity in which students are shown a model of Mars with its two moons, Phobos and Demos. They are asked to draw the phases of both moons as they would appear to an observer on Mars. When students take turns walking over to the model and looking at the moons from the position of Mars, nearly all are surprised to see that their drawings were wrong, with most being reversed left to right. The activity emphasizes how difficult it is to see the world (and moon phases in particular) from some else's point of view, even with the aid of a concrete model.

Schatz's curriculum resource for elementary and middle school teachers, with coauthor Cooper (1994), provides a series of activities based on constructivist learning theory. In the first activity, learners arrange a sequence of photos of Moon phases in the order that they think they will appear. Students then make a record of actual Moon phases over a month's time to see if they were right. This method is consistent with the theory that if students make their initial ideas explicit, it will be easier for them to extinguish any misconceptions when they compare their expectations with the real world. Finally, the students model Moon phases and eclipses by observing a ball (representing the Moon) lit by a lamp with a bare bulb (representing the Sun), using an approach similar to that described in section 1.4.2. That method of giving each student a model Moon was codeveloped in the early 1970s by Dennis Schatz and Larry Moscotti, then a planetarium director in Hibbing, Minnesota.

Duckworth (1987) used a Moon journal investigation with adult learners to illustrate two aspects of teaching.

> The first is to put the student in contact with phenomena related to the area to be studied–the real thing, not books or lectures about it–and to help them notice what is interesting; to engage them so they will continue to think and wonder about it. The second is to have students try to explain the sense they are making, and, instead of explaining things to students, to try to understand their sense. These two aspects are, of course, interdependent: When people are engaged in a matter, they try to explain it and in order to explain it they seek out more phenomena that will shed light on it. (123)

Duckworth's constructivist-oriented methods included varied attempts to help her students make sense of the phases of the Moon. She firmly believed that students must construct their own knowledge in order for this new information to become meaningful and therefore retained. Students compiled their observations and worked in collaborative discussions to describe the Earth-Moon-Sun system and to explicate their ideas. This method, according to Duckworth, led to students who achieved greater clarity of thought, who determined for themselves what they wished to understand for the lesson, who were independent, who learned from each other, and who had their own thoughts taken seriously.

Nissani’s 1994 description of his undergraduate assignment for learning Moon phases emphasized that his students arrive in an interdisciplinary college science course without a working knowledge of the Moon’s phases. His activity included students making Moon observations. He noted that students were expected to independently derive their conclusions from their own observations without the benefit of reference texts. He wrote, "inaccessibility of the answer is helpful; the text we use says nothing about the phases of the Moon. But it is even more important to encourage students to go it alone and to assure them that they are not expected to come up with a ‘correct’ answer and . . . they will be graded on the basis of effort, intellectual coherence, and creativity" (26). Nissani pointed to a critical issue: the tension between authentic inquiry and the pressure to grade students by commonly established means or methods. His paper included the complete inquiry activity of Moon observation, including step-by-step instructions for students.

van Zee’s 2000 study of scientific discourse during a Moon investigation included a cross-section of adult learners, including undergraduates, graduate students, and professors who chose to participate in the constructivist-based inquiry activity. Her analysis focused on the manner in which the science knowledge was generated within the constructivist framework of the course, but the subject under consideration from this diverse group was the phases of the Moon. Her hopes included the possibility that the course would work "to develop shared understanding through discussion" (115) and to shed light on the nature of science as a product of discourse. The study was guided by the following research questions:

1. What aspects of the students’ discourse indicated inquiry learning?
2. What kinds of questions do students ask each other during an inquiry discussion?
3. How do these students collaborate in making sense of their observations and interpretations?

Among her findings, the author noted that her role as an instructor was affected by the stated goal that the inquiry under discussion would be entirely student-generated. As an instructor, van Zee chose not to respond to student questions directly and avoided didactic teaching. She noted that her quietness in this regard had three aspects: to wait before and after students spoke, to listen to the details of others’ sense-making, and to withhold her own opinions on the nature of what was said. She detailed two modes of discussion: true dialogue, in which students talk with each other about what they think, and progressive discourse, in which clarifications are made and doubts are resolved. It is important to note that this study presented a course that had no astronomy-based science subject goals. As such, classroom authority was distributed within the group of adult learners, and there were no stated learning outcomes related to curriculum.

Abell, Martini, and George (2001) used a Moon phase investigation as an activity to deepen preservice teachers’ understanding of the nature of science (NOS). This study collected data through questionnaires, semistructured interviews, field note observations, and analysis of the documents generated by the class. Abell claimed that the Moon journal process parallels the development of other science activities by allowing students to make observations and collect and record data. Yet, in trying to teach an appreciation for the way in which science knowledge is generated, Abell discovered a tension with the science content of the subject. She found that only one student in her group of elementary education preservice teachers responded in terms of science as a collaborative effort. Abell noted, "Our findings show that student appreciation of the empirical, inventive, and social features of the NOS was limited primarily to processing their own learning, rather than applying their conceptions to the activities of scientists" (1106).

In a later work, Abell and colleagues (2002) described a Moon phases activity for preservice teachers in an elementary education methods class in which the goals included helping students to understand the phases of the Moon and their own learning, to enhance their understanding of the nature of science, and to have students evaluate their presumptions related to science teaching and learning. Abell and colleagues included a description of the "puzzlers" used to direct student inquiry during the Moon phases project.

Suzuki's work (2002) documented sophmore-level education majors in Japan as they worked on projects to teach the phases of the Moon for elementary students. The study included a focus on learning science through discussion and specifically mentioned that students at the elementary level have difficulty visualizing the Earth-Moon-Sun in three dimensions. Additionally, this paper mentioned that younger students build models based on their own everyday observations and that older students begin to synthesize their experience-based models with culturally accepted models. The model proposed by the course syllabus started with getting oriented and sharing observations. Students then compared their observations through time as the phases of the Moon evolved over a semester. Models of the system were later introduced, which allowed students to replicate the lunar phases using a globe and a flashlight. Suzuki's paper included self-report data and claimed that the group of adult learners had no initial difficulty with confusing the phases of the Moon with the Earth's shadow, but that there was a common assumption among the students to only look for the Moon during nighttime hours.

3. CONCLUSIONS AND RECOMMENDATIONS

The body of research reported here is remarkably consistent and rich in its implications for teaching and learning. While significant research questions remain unanswered, we can draw the following conclusions in response to the questions that framed this review.

3.1 Are the concepts of Moon phases and eclipses as resistant to change as indicated by the National Science Education Standards?

Yes. Alternative conceptions, or misconceptions, about the phases of the Moon are common and widespread among every sample studied in the body of research reviewed here, although the research samples differed in size, geographical location, age, and educational background. As Dai (1991) summarized, common misconceptions relate to the time of moonrise, the position of the Moon, lunar phases, and the model of the Moon-Earth-Sun system. One researcher noted a widespread assumption that the Moon is only visible during nighttime hours. Particularly common is the misconception that the phases of the Moon are caused by the Earth's shadow, a response that indicates confusion between the Moon's phases and lunar eclipses. As researchers who considered the impact of instruction reported, students' alternative conceptions about the phases of the Moon are resistant to change, although they can be affected through instruction.

3.2 At what age level should students learn how to explain Moon phases and eclipses in terms of a model of the Earth-Moon-Sun system?

Stahly et al. (1999) concluded that third grade is too young for effective instruction about the cause of the phases of the Moon. Barnett and Morran (2002) worked with fifth graders and identified a high number of alternative conceptions about the phases of the Moon, but these researchers reported a positive impact from instruction on students' ideas. Their research supports instruction about this topic starting at the fifth-or sixth-grade level. Nonetheless, Sadler's (1992) work with high school students and Trundle et al.'s (2002) success with preservice teachers indicate that instruction is usually necessary with older students as well. According to the available literature, even adult learners may benefit from opportunities to learn about Moon phases and eclipses.

3.3 What teaching methods are most effective in helping students acquire a dynamic mental model of the Earth-Moon-Sun that is consistent with modern science?

All the research studies reported in this article that considered the effectiveness of instruction at addressing students' ideas about the phases of the Moon support the conclusion that approaches based on constructivist learning theory are more effective than direct instruction approaches alone. This is especially true when students' prior ideas are taken into account. As Barrett and Morran (2002) concluded, "It was these prior student understandings that served as a foundation upon which they built more sophisticated understanding as the course progressed" (874). Activity-based methods that encouraged students to make their own observations and use models to figure out explanations were also superior to textbooks, two-dimensional images, and lecture-based learning. As Schoon (1992) pointed out, "For many students, the manipulation of physical materials, as well as discoveries made for themselves, help in retention of important information" (214).

Direct instruction about the phases of the Moon often involves illustrations that show the Earth and two sets of Moon images in eight different positions, both the "space view" from above the North Pole and the phases of the Moon as they would appear from Earth in each of the eight positions. Such illustrations are difficult for young children to interpret because they require the child to view the illustrations from two perspectives: one showing the view from space overlooking the Earth's celestial north pole, and the other Earth-based. In fact, the literature noted that even adults have difficulty interpreting these illustrations unless they already understand Moon phases. Older textbooks also included demonstrations in which the teacher would shine a flashlight on a ball to show the different phases. That demonstration was problematic because not all the children in the class saw the Moon ball from the same angle. Also, the teacher usually changed the phase by moving the flashlight, further confusing the demonstration. Other proposals suggest that each student receive his or her own materials for viewing the model activity, rather than using shared materials.

The finding that teaching methods based on constructivist learning theory were more effective than direct instruction is not surprising given the broad evidence that misconceptions in this area are widespread and resistant to change. At stake is an individual's understanding of the Earth-Moon-Sun system. Developing a dynamic mental model that allows an individual to interpret celestial phenomena is intellectually challenging. Direct instruction alone is simply not up to the task of engaging people in using their mental models to find out where they fail or are inconsistent and to construct new models of the Earth, Sun, and Moon in space. Meaningful activities for students are those that allow students' own ideas to be taken seriously. Constructivist-based learning environments provide these kinds of challenges for students. The literature suggests that the creation of meaningful activities leads to greater retention of science knowledge precisely because these astronomical models were developed by each student through personal efforts.

3.4 What are the implications of this research for curriculum developers and teachers?

The implications of this review for teaching and curriculum development are clear. While direct instruction may be efficient and effective at communicating easily learned information such as properties of the various bodies in the Solar System, constructivist methods are essential if students are to build an adequate mental model of how these bodies relate to each other.

The implications for assessment are even more important. The finding that so many teenagers and adults have persistent misconceptions about phases of the Moon and eclipses even though the concepts have been taught in elementary school indicates that assessment of these concepts during schooling has been absent or inadequate. Teachers at the middle school, high school, and even college levels are encouraged to ask their students to explain these and other elementary astronomical phenomena at the beginning of any astronomy course to be sure that their students have at least a rudimentary picture of the Solar System before going on to teach more advanced concepts.

3.5 What further research needs to be done?

Although studies that compared constructivist and direct instructional approaches came out in favor of the constructivist methods, the studies were not sufficiently detailed to tease apart the various components of instruction to see which were most important. For example, in constructivist methods, observations of the Sun and Moon are time-consuming. Would this part of instruction be more efficient if presented in a one-hour planetarium presentation? Or is it necessary for the students to gather data themselves in the real sky, as suggested by Duckworth (1987)? And if they do collect data over time, how important is it for them to first predict the pattern that they expect to see? What are the best ways to engage students in clarifying their own mental models and comparing them with the ideas of others and the actual phenomena?

A second line of investigation is suggested by the history of science. The Babylonians were the first to study patterns of movement in the sky, but they did not try to explain these movements in terms of a physical model. The ancient Greeks took the next step, developing a model to explain lunar phenomena, the Earth’s shape, gravity, and many other phenomena. This sequence is similar to that recommended by the National Science Education Standards; students at the K–4 level should be encouraged to observe changes in the sky and to seek patterns in the data, while students in grades five through eight should develop mental models that explain these phenomena. To our knowledge, no studies have been conducted to determine if students who observe the lunar cycle in grade K–4 are any better at developing modern mental models of the Earth-Moon-Sun in grades five through eight.

A third line of research might explore the relationship of students’ ideas about Moon phases and eclipses with their understanding of other astronomical phenomena. Stella Vosniadou and William Brewer (1992) conducted a series of studies of students’ understanding of the Earth’s shape and gravity and found that their understandings of these fundamental concepts were consistent with their explanations of a variety of phenomena, such as why we have night and day. It might be productive to explore the relationship between students’ explanations for Moon phases and eclipses with their ideas about satellite orbits and probes to other planets to see if strengthening their mental models in one area has benefits in understanding other ideas about the Solar System.

A fourth line of investigation would be to explore improvements in direct instruction related to Moon phases and eclipses. Although the research reviewed in this article provided no evidence that direct instruction helps people understand Moon phases and eclipses, it may be possible to devise clear explanations and illustrations that are at least helpful for adults who are used to learning through reading. An excellent article in a teacher's magazine might help some educators clear up their own misconceptions and help them in their astronomy teaching. However, before publishing such an article, it is important to test a draft in a controlled research study to determine whether it is effective and how it might be improved.

A fifth line of research would be to study how students' ideas change over time. Most studies are conducted within a very short time window, so we see how a group of students change their ideas as a result of experimental treatment and judge success based on aggregate performances on tests or interviews. Sadler (1996), for example, inferred from his research data that as students learn more about a subject, some increase their preference for certain incorrect explanations before they learn the correct scientific explanations. Longitudinal studies would test such hypotheses and reveal how students' ideas change over time. Such studies could determine if there is an invariant sequence of ideas leading to the modern scientific model, or if different students take different paths in their learning. Longitudinal research studies could be very helpful to teachers in customizing their teaching to different students' needs and in interpreting assessment data.

In conclusion, it has been gratifying to learn that several research studies support the recommendations in *National Science Education Standards* (National Research Council 1996) and *Benchmarks for Science Literacy* (American Association for the Advancement of Science 1993) that young children can observe the pattern of Moon phases, but teaching the explanations for phases and eclipses is best left until at least fifth or sixth grade. There is also convergence on the finding that although misconceptions about Moon phases and eclipses are resistant to change and widespread, even among adults, teaching methods based on constructivist learning theory can be very effective. While much research remains to be done, the findings reported here are not only robust, but also fruitful for immediate application by teachers and curriculum developers.

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Notes

Note 1: A lunar eclipse occurs when the full Moon moves into Earth's shadow. Solar eclipses occur when the new Moon passes directly between the observer and the Sun. Eclipses do not occur every month, since the Moon's orbit is inclined about 5 degrees with respect to Earth's orbit around the Sun. Lunar and solar eclipses occur about equally often, but an observer is more likely to see a lunar eclipse because anyone on the side of the Earth facing the Moon will see it slide into the Earth's shadow. Solar eclipses are rarely seen because the Moon's shadow traces a narrow path no wider than 100 miles. Only observers within the Moon's shadow see a total solar eclipse.

Note 2: Following Comins (2001), in this article, students' ideas that are inconsistent with the scientific explanation will be considered *misconceptions* or *alternative conceptions*, a term preferred by some educators for its neutral value.

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