The relationships of scale concepts on college age students' misconceptions about the cause of the lunar phases

by

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ABSTRACT

Considered to be a basic astronomy concept, the causes of the Moon's phases are taught in nearly every introductory astronomy class. Despite being a basic concept, students are full of misconceptions about the causes of the lunar phases. Students also fail to appreciate the scale of the Earth-Moon system. Most students underestimate the separation and/or overestimate the size of the Moon. If their scale model were correct, shadows would play a bigger role in the appearance of the Moon. This research was designed to quantify the extent of these misconceptions and to investigate whether there is a close relationship between having an incorrect explanation for the phases of the Moon and having an incorrect scale model.

CHAPTER 1. INTRODUCTION

Learning how students think and learn has been the focus of education research for decades. As long as there have been teachers, there have been new methods and ideas to help the teachers teach and the students learn. Education research has focused on physics relatively recently, with research groups forming to understand where students get stuck in physics and how to change this. Even more recent is the idea of applying education research results to astronomy, which has seen an increase in interest recently. Although there has been research on astronomy and physics topics, most had an education focus rather than a physics or astronomy focus.

The goal of this research is to try to understand exactly what the students think cause the lunar phases, and whether or not their mental models of the scale of the Earth-Moon system are related to their explanations. Previous research has focused primarily on pre-collegiate students and much of the previous research consisted of multiple choice diagnostics because of the problems with interviewing large numbers of students, such as the amount of time involved. Multiple choice diagnostics give answer choices to the students; all they have to do is pick one, which may or may not be what they truly think. Diagnostics such as this are limited to what the researcher may think the students' ideas are. Additionally, it is difficult to compare the results of younger students to the results of college students, since college students have had more exposure to scientific ideas and are better able to understand the world around.

What exactly makes this research different from previous research? First, the question on the cause of lunar phases is in free response format: students can say whatever they want to in the answer. Second, a link between students' comprehension of the lunar phases and their concept of the scale of the Earth-Moon system is researched. Some ideas the students have about the causes of the lunar phases would be very appropriate if the Moon was bigger than it is or if the Moon was much closer than it is to the Earth. Scale is the key to this problem. If it is possible to get students to realize just how small and how far away the Moon really is, then it may be possible to get students to accept and change to the correct explanation of the cause of the lunar phases.

For this project, student ideas on the causes of the lunar phases were collected before and after instruction. In addition, students were also asked, on the same survey, before and after instruction, to draw a scale model of the Earth-Moon system. The purpose is to test whether certain student ideas are tied to certain scale models. Therefore, if one can get the scale model of a student to change, one can get the student's idea of lunar phases to change.

The testing ground for this project was an introductory astronomy course focusing on the solar system, at Iowa State University in Ames, Iowa in the fall semester of 2000. There were roughly 400 students, of varying ages and majors in this class. More demographic detail is provided in Chapter 4, Table 8.

CHAPTER 2. REVIEW OF LITERATURE

Because the Moon is so close to the Earth and so prominent in the night sky, researchers expect students to be familiar with lunar phases and their cause. However, as the literature shows, this is not the case. Whether the focus of the research has been only on lunar phases, or on general astronomy knowledge, it has been shown that students, regardless of age, do not know what causes the Moon to have phases. Researchers have gone on to suggest various methods for helping students understand the correct reason for lunar phases. It remains to be seen how effective these teaching methods are in the long term.

Previous research seems to be focused primarily on younger students, around elementary school age, and on pre-service elementary education teachers. There is also heavy emphasis on the education side of the research, e.g. how does this fit into Piaget's model of learning. Various instructional methods have been suggested and tried, which seem to be effective over the length of the study. There are no long term studies to see if students can retain the information six months or longer from instruction. These different instructional strategies may be effective due to their intensive nature.

The following is a review of some of the relevant literature. If the literature gives the specific question used in the research, it is located in Appendix C.

2.1 Sadler

Probably the most referenced work in this field is Sadler's 1992 dissertation on the prior knowledge of high school students. Using a multiple-choice test, he surveyed 1,414 high school students from around the United States. Three questions from this test are relevant to this research.

Sadler's test question #2 showed diagrams of two different moon phases, observed a few days apart, and asked students to answer the question "*Why did the Moon change shape*?" The correct answer is not included among the five choices; instead the student must choose "none of the above" if the other four choices do not fit his thinking. A student with an unusual misconception would end up choosing this "right" answer. Most students, 41%, answered this question by choosing option B, "*It moved out of the Earth's shadow*." 27% of students chose C, "*It moved out of the Sun's shadow*." The next most common choice was the correct answer E, "*None of the above*", with 26% of the students choosing this response.

Sadler's question 11 showed five drawings and asked the students to choose the scale model that correctly reflects the size of the Earth and Moon and their distance apart. 40% of students chose options A or B, which portrayed the distance between the Moon and Earth as equal to about three Earth diameters. 46% chose options C and D, which showed this distance to be around 10 Earth diameters. Only 13% chose option E, which portrayed the correct separation of around 30 Earth diameters. It was also noted that many students, especially poorer scoring ones, answered that the Earth and Moon are roughly the same size.

What is most disturbing about Sadler's question 11 is its relationship to his question 15. Question 15 asked students to choose, from five options, a number that is the best estimate of the distance between the Earth and the Moon in miles. Most students chose the correct answer 100,000 miles; the next most popular response was a 1,000,000 miles. On question 11, students placed the Moon closer to the Earth than it should be while on question 15, they put it at approximately the correct distance or even farther away. This raises questions about students conceptual models. Do the students have accurate mental models? Is the reason more students answered question 15 correctly because they have memorized the facts but do not understand the concepts behind the questions?

2.2 Bisard, Trumper, Schoon, Zeilik

Along the same lines as Sadler's research, the most common kind of research on lunar phases has been a simple pre-test post-test situation, with a few papers reporting only pre-test findings.

In 1994, Bisard et al. did a cross age study of 708 students, the largest group of students being college freshmen and sophomores. An unusually large percent, 39.2%, of students answered correctly by choosing "The different shapes of the Moon (or phases) are caused by viewing reflected sunlight off the Moon during the month." Nearly as many (37.6%) said the cause was the Earth's shadow. 18.8% of the students decided that the cause of the lunar phases was the varying angle of sunlight off the Earth. The smallest percentage of students, 4.4%, chose clouds as being the cause of the lunar phases. Table 1 shows the percentage in each age group that chose the correct answer. Middle school students were least likely to choose the right answer while science education majors were more likely to choose the correct answer.

Table 1: Percentage of Students Correct by Age Group for Bisard et al (1994) (*N*=708)

Student Age	Percent
Middle School	34
High School	42
Introductory College Course	40
Upper level juniors and seniors	41
Science Education Majors	44
General Education Majors	41

Schoon did two studies on misconceptions about the Earth. The first study (1989) asked questions of 5th, 8th, and 11th graders as well as college students at two universities and a trade school. The second work (1995) surveyed pre-service elementary education students who had completed all coursework. Table 2 gives the number of students in each education range.

Schoon (1989) reported that the primary misconception held by students on the causes of the different lunar phases was the Earth's shadow on the Moon; which 48.1% of the students held. What he then reported is unexpected: the older the

Table 2: Students in Schoon's Study (1989, 1995)

Education Range	*N*	%
5th Grade	307	23
8th Grade	237	18
11th Grade	340	25
College	318	24
Pre-service Teachers	122	9
Total	1335	

student, the more popular this incorrect answer was. 69.5% of the college students in his study believed that the Earth's shadow caused the lunar phases. In his 1995 paper on pre-service elementary education students, he reported 62.3% believing the Earth's shadow caused the lunar phases. When the students in this survey were asked where this conception originated from, most responded they had always thought it was true or it just seemed like the right thing. Some also suggested that since shadows play a role in eclipses, shadows must be part of the causes of lunar phases. Schoon (1995) gives a table in which he lists where students believe their conceptions came from. The relevant part of his table is shown in Table 3. Out of 122 students, he only reports reasons from 28 students.

Table 3: Origin of Alternate Conception of Lunar Phases from Schoon (1995) (*N*=28)

	Taught in School	Taught other	Logical Reasoning	Other	"Always Thought"
Number of Students	3	5	4	5	11

Trumper (2000) used a question similar to Sadler's question #2, but added the choice, "The Moon moves around the Earth." Trumper considered this to be the correct response. He gave it to his introductory astronomy course of 76 students at a university in Israel. In this sample, 51.3% answered the question correctly with only 31.6% of the students choosing shadows as the cause. This high fraction of correct responses could be due to the high percentage (32%) of science majors in the course or it could be a reflection of the differences in education systems of Israel and the United States. Or it could be a reflection of the wording used in the correct response, which was quite different from that used by other investigators.

Table 4: Results from Zeilik et al (1995)

Question	Pre-Test % Correct	Post-Test % Correct	Gain
#4, scale	31	42	0.16
#15, Moon phases	31	66	0.51

In 1995, Zeilik et al. developed a forerunner to the Astronomy Diagnostic Test (ADT). Zeilik had begun changing his introductory college astronomy course for non-majors into a more interactive, conceptually based format and wanted to explore how well the 228 students were learning in this new format. Most of the students in his class were under 22 and were business majors. Question #4 asked about the scale of the Earth-Moon system, with a Moon a diameter of 6 cm. Question #15 showed 2 pictures of the Moon in different phases and asked for the reason behind the different phases. Table 4 gives the results from Zeilik et al's research.

Zeilik et al. described how the scale of the Earth-Moon system and of the solar system was specifically emphasized in class, with demonstrations and group discussions. Zeilik had thought that these methods were very effective; yet, the gain for this question was very small. No mention of instruction that placed an emphasis on the lunar phases is given in the paper. This is relatively surprising given the large increase in percent correct of this question, when most articles in the literature report post-test results with significantly smaller gains.

Zeilik and Bisard (2000) then gave a slightly longer version of the diagnostic used in Zeilik et al (1998) to roughly 1000 introductory astronomy students at two universities. They did not report pre- and post-test results, but rather the gain of the students. "Gain" was defined as actual gain (in percentage) divided by the total possible gain (also in percentage). The relevant questions to this research are number 4 and 21 in the diagnostic. Question 4 asked about the scale of the Earth-Moon system, while question 21 asked about the causes of the lunar phases. On questions 4, Central Michigan State, had a gain of 0.22 while the gain for the University of New Mexico was 0.26. For question 21, the lunar phase question, the gain of non-major students at Central Michigan State was 0.28, while the gain of non-majors at University of New Mexico was 0.45, giving an average gain of 0.36. These 2 questions covered concepts that are considered by these researchers as some of the most difficult concepts to change, because of the number of students holding onto their misconceptions after instruction. The most common misconception for the distance between the Earth and Moon is 10 Moon diameters, which 37% of students still held onto this conception even after instruction. The most common lunar phase misconception is the cause of the phases as the Moon moving into the Earth's shadow, with 27% of students still holding on to this misconception even after instruction. The authors do not discuss possible reasons for the large difference in the gain on the lunar phase question between the two universities.

2.3 Targan

Research in education has shown that students come to their courses with well developed ideas about the world around them and are very resistant to attempts to change those ideas. Targan (1993) and others studied the effects of specially designed instruction on students' ideas about the lunar phases. Instruction was specifically designed to help students abandon their incorrect ideas and incorporate new, more correct ideas into their thinking.

Targan developed a written instrument designed to encourage students to explain and draw out their ideas about astronomy. The lunar phase task of the instrument consisted of two questions, in which the first asked students to draw a cycle of lunar phases. Then, using this answer, students are asked to explain the cause of their cycle of phases. What is questionable about this approach is that if students can't answer the first question correctly or at all, they are unlikely to be able to answer the second question correctly. Of course, it can be argued that if students can't draw the phases in the correct order then they don't really understand the causes of the Moon phases. Targan's second question is listed in Appendix C.

Targan worked with 61 students in an introductory college astronomy course. He gave the students a pre-test, mid-test and a post-test to chart their conceptual change on subjects relating to the Moon. Table 5 summarizes his results. Targan places responses that give the cause of the phases as shadows into the eclipse category.

Table 5: Targan's Results (1993)

Model	Pre-Test		Mid-Test		Post-Test	
	N	*%*	*N*	*%*	*N*	*%*
Correct	1	2	2	4	11	20
Combination	1	2	0	0	0	0
Eclipse	8	13	21	44	5	9
Fragments of Models	13	22	21	44	35	65

No Model	37	62	0	0	3	6
Other	0	0	4	8	0	0
Total	60		48		54	

Targan's analysis is slightly confusing to the reader and ambiguous at times. After the reader has sorted through all the information he presents, it is possible to draw a conclusion from his work. Most students started his class with no discernable model and gradually develop different fragmented models. Students start making the conceptual change, but have not completed incorporating all the information into their models correctly. What could possibly be happening is students learn new information without disregarding the old information and merge all of the information into a model that is partially correct and partially wrong.

2.4 Spatial Ability and 3-D Modeling

Several studies have focused on the spatial ability of students in conjunction with their lunar phase models. Does the student's ability to see things in three dimensions impact whether or not they understand the causes of lunar phases and does their spatial ability play a role in this understanding?

Reynolds (1990) took a group of 52 11th grade physics students and theorized that students who modeled the Earth-Moon system in three dimensions meant that the student understood the causes of lunar phases. His research design consisted of 26 like sex pairs of students to which he gave two packs of eight cards. On the cards were various lunar phases, each pack of eight being a complete lunar cycle. He asked the students during interviews to put these cards in the correct order. Only 2 pairs were able to get the phases in the correct order. Once the students ordered the lunar phases, they were asked the cause of the lunar phases. He noted what materials, like balls or paper cut-outs, the students used when explaining the cause of the lunar phases. The results from his interviews suggest that students who use three-dimensional models to describe the causes of lunar phases are more likely to be correct in their explanation.

Wellner's 1995 dissertation contains an in-depth look into the projective spatial skills of college students majoring in science; she proposed that these skills are necessary for students to construct correct physical and mental models of the Sun-Earth-Moon system. The ability to build a model, using external and internal perspectives to explain it, while having the model rotate at the same time in one's mind are known as projective spatial skills. The masking of an object by another is an additional skill in this set. She proposes that the reason students do not understand the cause of lunar phases is because the subject is not being taught at the developmentally appropriate age. Citing work by Piaget and others, she suggests that until about age 13 and older, students do not have the spatial ability to understand lunar phases. Therefore she suggested not teaching the lunar phases until students were developmentally ready.

Wellner's research was conducted with 61 undergraduate science majors at a small private college in the Midwest. The first task the students were asked to do was to take a collection of variously shaded Styrofoam "Moons" and place them around an Earth, justifying the placement of each Moon. More questions on the placement of the Moons were asked to make sure the students had not just memorized the lunar phases but rather had an understanding of some sort of the cause of lunar phases. If the student was successful on the first task, a second task was then given, involving a set of 4 cards each showing a lunar phase. The student was asked to set up the model so that the lunar phase on the card could be seen in their model.

Out of 61 students, only 22 were able to do the first task correctly. Only one student was able to complete both tasks correctly. Of the fifteen students who had taken a previous astronomy course, only 8 were able to pass the first task.

After the model had been set up, the students were questioned on the causes of the lunar phases. Responses in this research differed from other research asking a similar question. Thirteen of the students proposed that lunar phases were caused by the Moon not being directly in front of the Sun and therefore received indirect light. Eight students thought that the farther away from the Sun, the darker the Moon is thereby causing the phases. Only three students suggested that the Earth's shadow was involved. Two students thought that sunlight bouncing from the Earth to the Moon causes the Moon to be illuminated.

Wellner concluded that the ability to construct and explain the lunar phases correctly was directly related to the amount of projective spatial skills a student possessed. She proposed that by looking at lunar phases within a spatial skills framework will instructors will be able to give students a better chance of understanding the causes of lunar phases.

Callison (1993) tied the works of Targan and Wellner together. Similar to Wellner, Callison believed that to understand the phases of the Moon, a student must be able to use spatial skills to mentally visualize the Sun-Earth-Moon relationship. The goal of her work was to determine whether or not certain instructional strategies focusing on spatial abilities had an effect on students' explanations of the phases of the Moon.

Using Targan's test, Callison tested 76 mostly female, pre-service elementary teachers three times, a pre-test, a post-test and a retention test. She also did interviews with 30% of the students, participants being randomly selected.

The students were divided up into 4 groups with each group receiving a different treatment, ranging from concrete to abstract. Three of the groups received instruction designed to help students build mental models; the fourth group received traditional instruction.

Her results are summarized in Tables 6 and 7. She found that students generally moved from no model to fragments of a model to a more correct answer. The alternate model includes blocking, shadows and other explanations. She concluded that students need help building mental models and that instruction that incorporated this process into teaching would be more effective.

Table 6: Callison's (1993) Survey Results for all Treatments

Model	Pre-Test		Post-Test		Retention Test	
	N	*%*	*N*	*%*	*N*	*%*
Correct	5	6	17	22	16	25
Alternate	13	17	14	18	10	16
Fragments	19	25	37	49	26	41
No Model	39	51	8	11	12	19
Total	76		76		64	

Table 7: Callison's (1993) Results from the Interviews for all treatments (*N*=22)

Model	First Interview		Second Interview	
	N	%	*N*	%
Correct	0	0	11	50
Alternate	14	64	3	14
Fragments	4	18	7	32
No Model	4	18	1	5

2.5 Other Research

The next most popular kind of research involves pre-testing, treatment and post-testing. Most treatment is designed to promote conceptual change using whatever educational methods are in favor at the time of the research.

The youngest age to be studied were third graders by Stahley et al (1999). It may seem that work done on eight-year olds is hardly significant to work done on college students but when looking at the conceptions these children have, the conceptions don't change as the students get older. The most frequent causes of the Moon phases that the researchers found were: 1. clouds, 2. shadows of some kind, 3. the shadow of the Sun on the Moon blocking the Moon, 4. the shadow of the Earth on the Moon blocking the Moon and 5. the correct idea. The only answer that seems to lose favor as students grow older is the idea that clouds cause the lunar phases, as also noted by Bisard et al. (1994).

One thing that is unique about Stahley et al.'s work is their concern that all of the students' conceptions should be identified, even if they were not on the multiple choice test. To make sure that all ideas were included, they gave a written survey to 21 students and made 4 in-depth interviews.

Baxter (1989) studied the astronomical conceptions held by 100 students, ages 9-16 in the United Kingdom using a multiple-choice diagnostic. These students had no previous formal astronomy instruction. The answer choices to his questions consist of a series of different faces, with the happiest face representing the answer, "I know this to be true." Baxter found that students held one of five notions about the phases of the Moon. Three of these notions involved a shadow of some kind falling on the Moon. Figure 1 is a reproduction of his Figure 6, listing the notions with pictures. Baxter gives the frequency of the answers by age in his Figure 7 which is reproduced here as Figure 2. Baxter concludes that the early notions of students are based largely on their observations.

Confusion over causes of the lunar phases is not just an American phenomenon. Dai and Capie (1993) surveyed pre-service elementary education teachers in Taiwan on their ideas of what causes lunar phases. Dai and Capie developed 25 multiple choice questions which they gave to 174 students. Along with lunar phase misconceptions, the researchers looked to see if student conceptions could be connected to gender, religion or major.

One major drawback is that exact questions and answer choices are not given in their paper, only statistical values for each choice are reported. Some of the more common responses, according to the researchers, are the shadow of the Earth causing the lunar phases, changes in the amount of sunlight reflected causing the lunar phases or that a change in the area that is reflecting the sunlight causing the lunar phases.

As to any connections that can be made between responses of the causes of lunar phases, gender, religion and major, the researchers assert that the sample size is too small for accurate statistics. Barring that, Dai and Capie note that there

Figure 1. Taken from Baxter (1989)

Figure 2. Taken from Baxter (1989)

was no difference in responses based on gender but that there were differences in responses based on religion and major.

Skam (1994) gave 81 pre-service primary teachers a series of statements about different astronomy concepts and asked them whether they agreed or disagreed with the statement. The statement on the causes of the lunar phases was "The Moon changes shape because of the varying amounts of the Earth's shadow cast upon it." Of the 81 students, 59.3% disagreed with this statement. 42% of those students were able to give a partially correct answer and only 35.8% of students who disagreed with the statement were able to give a fully correct reason. Again, very few students know the correct cause of the lunar phases.

Lightman and Sadler (1993) looked at teacher predictions of student knowledge versus students' actual knowledge. They wanted to know how well teachers could predict the students' abilities to overcome their misconceptions. Lightman and Sadler believed teachers did not understand the strength of students' previous ideas and that teachers were unaware of the existence of these previous ideas. Using 16 questions from Sadler's 1992 dissertation, the researchers asked 66 teachers how well the students would perform on the test before and after instruction. The average grade the teachers taught was 9.5. Lightman and Sadler then gave the questions to 330 9th and 10th grade students before and after instruction. The teachers predicted that 33% of students would know the correct cause of the lunar phases before instruction and that 72% of students would know the correct cause after being instructed. In reality, approximately 25% of students responded correctly to Sadler's test question #2 on the lunar phases on both the pre- and post-tests. Teachers overestimated student gain on this question by 47%. What the researchers found was that most teachers believe their courses are highly effective, which is not always the case.

The prevailing misconception common to all research is that lunar phases are caused by the shadow of the Earth. Researchers and teachers are aware that this misconception persists despite all attempts to eradicate it. Why does this misconception refuse to go away? It is time to look at the problem from a different angle.

None of the previous research mentions the scale of the Earth-Moon system in conjunction with lunar phases. Callison does suggest it should be an area of further research. Furthermore, the majority of previous research is based on multiple choice exams, which can have the idea that the student holds or not, which means the student may not be able to choose an answer that reflects their ideas.

When looking at textbook diagrams used to explain the cause of the lunar phases, the scale of the Earth and Moon are brushed aside. The captions with the diagram almost never mention that the picture is not to scale. *Voyages to the Planets* (Fraknoi et al 2000) does mention that the distance in the picture is not to scale, but fails to mention the size of the Moon. *Voyages to the Planets* also includes a picture of the Earth-Moon system drawn to scale but is in a completely different chapter from the Moon phases. The textbooks do not appear to place an emphasis on scale in conjunction with the lunar phases. Most of these diagrams use very distorted distance scales placing the Earth and Moon very close. A sample of textbook lunar phase diagrams is included in Appendix D.

CHAPTER 3. METHODS

This chapter covers the development of the diagnostic along with its administration. Instruction that all students received, traditional instruction, is described as is special instruction received by a small sample of students. Discussion is also included on the methods used to sort and analyze students' responses.

3.1 Development of Diagnostic Survey

The diagnostic survey used in this research began being developed in Spring 2000. A final version of the survey was developed and given twice in Fall 2000. One of the questions on the instrument, the scale question, underwent a slight revision in the middle of the semester. Both versions of the diagnostic can be found in Appendices A and B. The survey contained only two questions, one on the causes of the lunar phases and one on the scale of the Earth-Moon system.

The diagnostic was designed to test the hypothesis that misconceptions about the scale of the Earth-Moon system contribute to the students' incorrect ideas about the causes of the phases of the Moon.

3.1.1 Lunar Phase Question

In Spring 2000, fifty student volunteers were interviewed. These volunteers were students in the introductory Astronomy and Physics classes at Iowa State Univeristy. Information sheets were handed out in these classes to solicit volunteers. Some volunteers were promised extra credit in their classes if they participated. The videotaped interviews were approximately twenty to thirty minutes in length and covered a variety of basic astronomical concepts. Questions were asked on the causes of the seasons, the reason for lunar phases and on the causes of eclipses. One specific question asked was, "Why does the Moon change night after night?' A large piece of paper, markers and balls of various sizes were available for the students to use during the interview. The transcripts of the portions of the interviews that related to the lunar phases are in Appendix F.

During the interviews, the students were asked to draw a cycle of lunar phases. Some students did not know there were lunar phases and needed help completing the question. Some students did not know what the term lunar phases meant and others did not realize that the Moon had phases. For these students, the term lunar phases would be explained or questions were asked to try and get the student to realize the Moon had phases. A line of questioning to help students would often start with, "If the Moon looks like this on Sunday, (drawing of a Moon phase) what would the Moon look like on Saturday?" In their explanations of the causes of the lunar phases, the students would often refer back to their drawing of the lunar phase cycle. Therefore, it was essential that an illustration be included as part of the question.

That same semester, written instruments were given to various classes; these classes consisted primarily of non-science majors. Surveys were given to the introductory astronomy class that covers the solar system, to a class on various teaching methods for elementary science teachers and to a beginning education class. The following question was asked: “Why does the Moon change shape night after night?" From looking at a sample of answers, it was clear that the question in its current form was not specific or detailed enough, because the answers students gave tended to be short and not very illustrative. Student responses were similar to the statements "It has phases" or "because of the shadow." It was hard to tell exactly what they were thinking because the students didn’t give very detailed explanations with their answer.

For Fall 2000, a different approach to the question was needed to get more detailed responses from the students. The question would need to be sufficiently open-ended so that students would be able to communicate exactly what they thought. No scientific terminology would be used, in case the students did not know what the words meant. There was also concern that students would try to work these scientific terms into their answer even if it was irrelevant. Additionally, diagrams would be used to help convey the meaning of the question to the students. Finally, students were asked to clearly explain their answers. The question had a diagram of a full Moon and of a crescent Moon and asked "*Explain, as clearly as* *you can, why it is that the Moon sometimes appears as a full bright circle like this (diagram of full Moon) and sometimes the Moon can appear as a crescent like this (diagram of crescent Moon)."*

For the most part, this approach worked. Student responses were longer and more descriptive than responses given on previous diagnostics. Additionally, some students gave an explanation for each diagram that helped pinpoint their understanding and their thinking. For this version of the question, responses that just stated the names of the phases of the Moon (full, quarter, new, etc) were decreased.

It appears that simply asking “What causes lunar phases?” is not the best way to get a sense of what students are thinking. Student responses to this question are short, less descriptive and contain totally irrelevant information. When asked the question about lunar phases in that form, students tend to answer "because it goes from full to third quarter to new to first and then to full" without ever really answering the question.

3.1.2 Scale question

When students were interviewed in Spring 2000, they were given an assorted collection of balls of various sizes and told to pick two balls out to use to make a scale model of the Earth-Moon system. This approach ran into problems rather quickly. First, some students did not like the choices of balls. They felt that the size they needed was not available. Second, it was difficult to measure the distance between the balls during the interview. Third, students did not quite understand what a scale model was. This involved a fair amount of explaining using train sets and toy cars as examples. Many students only gave the scale of the diameters of the Earth and Moon and neglected to do the scale of the distance and would need to be asked again for the distance between the Earth and Moon.

The problem with giving students a collection of balls is, as noted earlier, that it restricts the student’s choices. If they thought things were larger or smaller they had no real way to represent this. Additionally, some students thought that the Moon was so small as to be seed sized. It wasn’t practical to use seeds as they are very small and therefore hard to manipulate. Students who couldn't find the balls to match the their mental models were forced to adapt their models to what was available. This meant it was harder to get a true idea of what the student actually thought.

On some of the written surveys that were given out in Spring 2000, the question of scale was asked. Because it was not possible to give the students balls to work with, students were given a scale to work with, similar to previous research. The students were told to assume that the Earth was a certain size and then decide how big or small the Moon would need to be on that same scale. How far apart would the two objects then be on this scale? This worked mostly except for some problems. One, the students did not explain clearly why they said what they did. Second, by giving them a scale, it forced the students to use a little math. Giving questions that involve math to students in an introductory non-major science class can be problematic because these students are not very familiar with math and have a hard time applying the math they do know. Finally, it was restrictive to the student. By setting the scale for the student, the question stopped being open-ended. The student had to try and think the same way as the researcher to answer the question. If a student had a concept for the scale model of the Earth-Moon system that was not the same as in the question, the student would then be forced to try and adapt their model to answer the question. This was not the desired outcome of the question. What was wanted was an open-ended question that would allow students to construct their own scale models thereby allowing students to express their thinking.

For the written survey for Fall 2000 the students were not given a scale but were invited to choose their own scale. They were asked to draw a scale model of the Earth-Moon system on an 8.5 inch by 11 inch piece of paper. Originally, a larger piece of paper was considered, but the larger paper would not completely fit on the students' desks. In addition, the term "scale model" was defined in case the student was unfamiliar with the term. The question is as follows, "*On the back of this page, draw the Earth-Moon System as a scale model. (This means draw the Earth and the Moon the correct sizes relative to each other. Also, make sure to show the*

Earth and Moon the correct relative distance apart from each other.) Don't worry about being too accurate. Please explain why you drew the Earth-Moon System the way you did." The students were directed to scale both relative size and distance between the them, however it is possible that many students just decided to do one part of the question, scaling the size of the Earth and Moon neglecting to also scale the distance between the Earth and the Moon. Perhaps splitting the question into separate parts would be more effective. For example, in the first part of the question the students could draw the Earth and Moon to scale ignoring the distance between them. In the second part of the question, the student would then take their Earth and Moon from the first part and put them the correct scale distance apart. This would ensure having the student answer both parts of the question, giving much more accurate information.

As part of the question on scale, students were asked to explain why they drew the scale model the way they did. Most students wrote something along the lines of “because that is the way it is” which is not very illustrative or descriptive. In future versions students may be encouraged to draw the Earth and Moon as circles because of the number of students who drew ovals.

There was a minor wording change in the question between early fall and late fall. During the first round of questioning, it was noted that students did not label the items in their drawings and it was difficult -- sometimes impossible -- to tell which circle represented which object. For the second round of questioning, students were asked to label all the items, eliminating the problem.

3.2 Administration of Diagnostic

3.2.1 Early versions

An early version of the diagnostic, without the scale question was given in Spring 2000. Students were given 15 minutes to complete the survey. The diagnostic was given before any exposure to lunar phase explanations in class. The results of this version are not reported here but were used to help develop the current version of the diagnostic.

3.2.2 Current Version

The current version of the diagnostic was administered twice in Fall 2000 to an introductory astronomy class. The first time the survey was administered was at the beginning of the semester before lunar phases were covered in class. This will be referred to as the "first survey' throughout the rest of this research. The second time was during the last class meeting of the semester. This will be referred to as the "second survey." In both cases, the students were given roughly 15 minutes to complete the survey. The survey was given out in the recitation classes, which have about 25 students in each class. The surveys were given to students during the Friday or Monday class. Recitation instructors were directed to give the students 15 or so minutes to complete the survey. Instructors were also told not to help the students answer the questions, but instead tell the students that the surveys were not graded. An additional multiple-choice diagnostic was also given at this time entitled "Moon Concept Inventory." The diagnostic was developed by Rebecca Lindell Adrian (2000) and focused on the Moon. This Inventory was given to the students immediately after they turned in their responses to the first survey, and they turned in their answers during that same class period. It is hoped that the diagnostic can be given for the third time to some of these students at a later date.

3.3 Instruction on Lunar Phases

3.3.1 Lecture

Lunar phases during the Fall 2000 introductory astronomy class were covered in the traditional manner. The lecturer used diagrams found in the textbook and explained the causes of the lunar phases, spending roughly 30 minutes on the material.

Additionally, students were given a homework assignment in which they had to scale the solar system by using an Earth diameter of 12 inches. Students had to find the diameters of the other planets and their distances from the Sun on this scale. The Moon and its distance from Earth were also included in this scale model.

3.3.2 Recitations

Along with lectures, Iowa State University's introductory astronomy course has an additional required small class meeting each week. For Fall 2000, there were 17 sections of about 25 students each. All 17 sections reviewed the material presented in class on the lunar phases. In addition, five sections were presented with special material that focused on the scale of the Earth-Moon system in relation to the lunar phases.

For the special activity, students were presented with two lab stands that had balls hanging from them. One ball was bigger (D = 3.5 inches), representing the Earth, and the other ball was smaller (D = 1 inch), representing the Moon. These balls were roughly the right proportions, since the Earth's diameter is 3.7 Moon diameters. Two students were selected to hold the Earth and the Moon in the air and then instructed to stand next to each other. The instructor then explained that the Earth person would remain stationary while the Moon person would move. It would be up to the class to decide when the Moon was far enough away. As the Moon person moved, the class discussed and finally agreed upon where the Moon should be in relationship to the Earth. The instructor then asked the students if they were positive. The instructor would then move the Moon person to the correct spot, which had been measured previously. Except for one section, the Moon person had to be moved farther away. The students were impressed; the demonstration appeared to give them a more concrete understanding of how far away the Moon truly was.

Now that the Earth and Moon were the correct distance apart, they were set on the ground and the Sun was brought in, represented by a 150 Watt floodlight. The Sun was put far enough away that its light would still shine on the Earth and Moon. To simplify matters, the Earth, Moon and Sun were assumed to be on the same plane. The Earth did not orbit the Sun or spin on its axis, nor did the Moon have any motion. The students were then encouraged to walk around this set-up for an external view. As the students walked around, they were asked about shadows and to notice whether or not shadows were present on any of the objects. Students discussed what, if anything, was between the Earth and Moon, and agreed that there was nothing between them. These points were stressed because preliminary results from the first survey showed that these were common conceptions with these students. By explicitly pointing out evidence to the contrary, it was hoped that these conceptions would lose favor with the students.

Based on previous research, students would also need an internal view of the Earth-Moon system. The Earth ball was replaced by a group of five students, who now represented the Earth. The Moon ball was then walked around so that the student "earths" could see the phases. As the Moon went around, the students were asked to point out the shadows. Some students in some of the sections commented that the Moon ball was too small to see, so a rubber children's playball (D = 6 inches) was used instead. Using this larger ball unfortunately pulled the model out of scale, which the instructor did not realize at the time. It was natural for the instructor to change the size of the ball to help the students visualize the lunar phases. In order to make the lunar phase concept clearer, the scale concept was skewed. This model of the Earth-Moon system was no longer in scale, either in distance or in size. Again, the Moon went around the student "earths" and the shadows were to be pointed out. The students were asked directly to point out the shadows or tell the instructor when they saw a shadow. A few students verbally acknowledged that there were no shadows and there appeared to be a general consensus from the rest of the students, as no students objected to the idea of their being no shadows in the demonstration.

By addressing the students' conceptions directly, it was hoped that they would experience displeasure with their conceptions and form a more scientifically acceptable view. Additionally, students were encouraged to participate in these activities to help them construct their own knowledge on the causes of the lunar phases.

3.4 Analysis of the First Question

The first question on this diagnostic asked students to explain the causes of the lunar phases. After previewing a random sample of the surveys, the surveys were grouped by similarities, without giving names to the groups. Thus, there were no pre-determined categories for the responses before they were examined. The student responses, at first, were sorted by either a prevalent idea, e.g. sunlight reflecting off the Moon, or by a certain word such as "shadow." Students' responses tended to fall into certain groups which then became the categories. One of the biggest problems faced during the sorting was that student responses tended to be ambiguous. It was hard to know exactly what they were trying to say. Some responses could have been categorized one way or another depending on the interpretation of the wording contained in the response. The responses were then sorted a final time into the various categories.

Using the categories defined in the first set of surveys, the second set of surveys was sorted this way. There were some categories that were present in the first survey but not in the second survey, such as the *Position of the Sun*. Also, some categories had to be added because there were responses that did not fit into the categories determined from the first survey. Additionally, it was decided that some of the categories needed further refinement. For example, in the first set of surveys, students who responded that the lunar phases were caused by sunlight reflecting off the Moon and the Moon rotating were just placed in the *Sunlight Reflecting* category. When the second set of surveys was categorized, it seemed better to make this its own separate category based on the larger number of responses that combined these two ideas as it seemed to help clarify student conceptions. Therefore, a new category was created and called *Reflection of Sunlight and the Motion of the Moon*. Although it would seem that a response similar to the one given should be placed into the *Combination* category, it was easy to isolate the main ideas in this response, whereas, in the *Combination* category, there were quite a few ideas mixed together in a response.

Originally, there were 23 categories. However, many of these categories contained very few student responses thereby making them less significant. It is important to note however, that there are students who believe some very strange things about lunar phases.

3.5 Analysis of the Second Question

Analysis of the second question was the same for both sets of surveys. A transparency of concentric circles, from 0.05 to 6 inches, was used to measure the diameter of the drawn Earth and Moon. From 0.05 inches to 1.5 inches, the circles were drawn every 0.1 inch. For students whose Earth and Moon were not circular, an average of the major and minor axes was used. The distance between the drawn Earth and Moon was then measured in inches using a ruler marked in tenths of inches. Distance was measured from the closed edge of one object to the closest edge of the other object. The same ruler and transparencies were used for all the surveys. If a student stated a numerical value for the drawings, for example the Moon is 100,000 miles away from the Earth, this was noted but not taken into account when measuring the drawings. The ratio of Earth diameter (E) to Moon diameter (M), E/M, was calculated as well as the ratio of the Earth-Moon distance (d) to the Earth diameter, d/E.

CHAPTER 4. RESULTS OF RESEARCH

This chapter presents the results of the research. Results are discussed in Chapter 5. All tables, unless noted, are in percentage of students. Additionally, there are three different groups of students, meaning there are six sets of surveys. Group A consists of the entire sample of all students. Group B consists of students who took both surveys and received traditional instruction while Group C consists of students receiving special instruction who took both surveys. Group A1 represents the students who took the first survey, regardless of instruction received and regardless of whether or not they completed both surveys. Group A2 represents all students who took the second survey, regardless of the instruction they received. Group B1 represents the first surveys of students who took both surveys and received no special instruction. Group B2 represents the second survey responses of the same students in Group B1. Group C1 represents the first surveys of students who took both surveys but received special instruction. Group C2 consists of these students' second survey results.

4.1 Demographic Information

Demographic information, such as age, was gathered on a voluntary basis during the first survey in Fall 2000. Iowa State University is a large land-grant university, the student population reflecting the population of Iowa. Table 8 summarizes the demographic information. As the table shows, the typical student in this class is under twenty, probably a freshman or sophomore, from a small town that has had pre-calculus. Furthermore, this typical student majors in business and believes she is average in math and science.

4.2 Description of the Categories for the Responses to the First Question

The responses were for the most part classified by the words they contained. Responses that said "shadow" went into the *Shadow* category and so on. Not all student responses were as easy to classify as the *Shadow* or *Blocking* categories.
Table 8: Demographic Information on Students (*N*=414)[a]

Category	Percent of Students
College Major	
Business	27
Education	18
Humanities, Social Sciences or the Arts	22
Science, Engineering, Agriculture or Architecture	12
Other	21
Age	
0-20 years old	81
21-23 years old	14
24-30 years old	4
31 or older	1
Gender	
Female	55
Male	44
Declined to Answer	1
Home Community	
Rural	17
Small Town	40
Suburban	22
Urban	18
Outside U.S.A.	1
Highest Math Class Completed at Time of Survey	
Algebra	15
Trigonometry	16
Geometry	15
Pre-Calculus	29
Calculus	24
How Good at Math Are You?	
Very Poor	2
Poor	11
Average	44
Good	34
Very Good	8
How Good at Science Are You?	
Very Poor	2
Poor	7
Average	51
Good	35
Very Good	5

[a] Reponses came from students who took the first survey.

Most responses were ambiguous and their classification depended on how the responses were interpreted. Many of these responses had elements of the correct answer in them but either left out a critical element or put in irrelevant information. Because these responses were so difficult to classify in a simple way, each response was classified by a general theme rather than one or two specific words.

4.2.1 Correct Category

This category contains responses that are generally correct. The student had to show that she understood the cause of lunar phases to be the relevant positions of the Sun, Earth and Moon, the angle of Moon as seen from the Earth, or some other description that was along those lines. Any responses that included a correct explanation along with words like "shadow" and "blocking" were placed in the *Shadow* or *Blocking* categories rather than in the *Correct* category. The idea was to have responses that were unambiguously correct in this category. Sample student responses are as follows (all answers are given verbatim):

> “The Moon appears to have different shapes because of the way the Sun is hitting it. Also, since the Moon revolves around the Earth we can see it from different angles, therefore we only see a partial of the lighted area most of the time which in turn appears to make the Moon change shape”

> “It appears differently because of the Sun Earth Moon allignment [sic]. How the Moon reflects the Suns light and where the Earth is located. If the Sun is directly lined up with the Moon we get a full Moon or a new Moon if is at angles, we get a crescent or a gibbiouses [sic]'

> “it will appear whole because of the angle between the Moon and the Sun is larger, reflecting more light off the surface of the Moon facing the Earth. As the Moon revolves there is a smaller angle causing less of its surface to be illuminated”

4.2.2 Shadow Category

This category includes responses that have the word “shadow“ in them, for example, "because the Earth’s shadow falls on the Moon." This was a fairly clear-cut category as any response that had the word shadow in it was immediately placed in this category. This category was then subdivided into specific causes of the shadow, represented in Table 11. Not all students think that the Earth's shadow causes the lunar phases; some students think it is something else like the "shadow of the Sun." Sample student responses are as follows:

> "During our Revolution Around the Sun The Moon is Also in Orbit with the Earth. Hence when the Earth is NOT Between the Sun and the Moon It Appears FULL. When the Earth is Between the Sun and the Moon You See the Earths [sic] SHADOW."

> "The Moon goes around the Earth as the Earth goes around the Sun. As the Moon revolves, the Sun cast's [sic] light onto the Earth and the Earth shadow goes onto the Moon. Depending on where the Moon is, it will look like the Moon is in different shapes"

> "Because of the Earth's shadow across the Moon"

4.2.3 Blocking Category

This category consists of student responses that contain the word "blocking" or the phrase "covered up" in their explanation. The students said that different objects were doing the blocking, such as the Sun and the Earth. The different causes of the blocking are given in Table 12 for Group A. Because this category had not been seen in previous literature, it was rather surprising that this *Blocking* category would be needed in this research. It is not clear if students who gave the explanation for the cause of the lunar phases as "blocking" really meant to say "shadow." It is possible that the students meant to say that the shadow is blocking the sunlight from reaching the Moon. However, students did not write that. There is no way to find out for this sample of surveys what these students really meant. Therefore it is assumed that when a student gives blocking as the explanation, it is different from giving "shadow" as the reason. Sample student responses are as follows:

> "The Moon would appear to be full when the Earth is no where near the path around the Sun to block sunlight from reflecting on the Moon. It would appear crescent when the Earth crosses through the orbit in which the Moon receives sunlight."

> "It appears differently because the of where the Sun is in relation to the Moon and how much of the Moon the Sun is blocking."

> "A full bright circle indicates a full Moon which means the Moon is receiving all the Suns' [sic] light without any object (planet) in the way. A crescent Moon indicates that the Moon is in between phases (the Earth is blocking some of the Sun's light. [sic]

4.2.4 Reflection of Sunlight

This category contains responses that include the phrase "sunlight reflecting" or the "Sun's light hitting the Moon" or some other phrasing to that effect. It is not always clear whether the students mean that the lunar phases are caused by the Sun's light reflecting off the Earth or that they are caused by the sunlight reflecting off a portion of the Moon. These responses may seem somewhat correct but are missing a key element, like position of the Moon or Earth. Sample student responses are as follows:

> "because it depends on how much of the Sun is shining on it and what part the Sun is shining on it"
>
> "It just depends on how much the Sun is reflecting off of the Moon."
>
> "The Moon shows up because it reflects the light of the Sun. It has cycles it goes through. And at different times, more light is reflected than at others."

4.2.5 Motion of the Earth

Student responses in this category explain the causes of the lunar phases by the motion or movement of the Earth. Many students said that the Earth moving in the sky or around the Sun was the primary cause of the lunar phases. To be placed in this category, the response must have mentioned either the rotation or revolution of the Earth or included some phrasing that conveyed the idea that the Earth was moving. Responses in this category do not included anything about sunlight reflecting off the Moon.

One problem encountered in this category and other categories dealing with motion during the classification of responses was students' use of the words "rotation" and "revolution." In normal conversation, rotation and revolution can be used interchangeably, but in astronomy these two words have very specific meanings and can not be interchanged. In astronomical usage, rotation refers to an object spinning on its axis, while revolution refers to the motion of one object about another. It was clear on both sets of surveys for all groups that students did not understand the difference in usage of rotation and revolution and used them interchangeably. It was not really possible to tell which word the students really wanted. Because of this, students who used the concept of rotation or revolution to explain the cause of the lunar phases were grouped together under the heading "Motion."

> "Because the Earth is moving the Moon can get out of the sight of the Earth during its different rotations."

> "It all changes as the Earth rotates. The position of the Earth will make a difference on how the Moon looks."

> "It is because of the rotation of the Earth. As the Earth rotates it allows you to see what is visible from where you are."

4.2.6 Motion of the Moon

Students in this category gave responses that indicated the rotation (or revolution) of the Moon is the primary cause the lunar phases. To be placed in this category, the responses had to mention either the rotation or revolution of the Moon or some phrasing that meant the Moon was moving. Including responses that said either rotation or revolution was necessary for the reasons described in the previous category. because it was doubtful that students understood the difference between them. Sample student responses are as follows:

> "The appearance of the Moon has to do with the rotation of the Moon"

> "Because of the Moon is going in a rotation, changing in every-period. [sic]

> "The Sun's rays strike the Moon and due to the synchronous rotation we only see one side. As the Moon orbits the Earth, the phases change"

4.2.7 Position of the Moon

In this category, students explained that the causes of the lunar phases were due to the position of the Moon. To be placed in this category, responses had to include the phrase "position of the Moon" and nothing else that could be considered a cause of the lunar phases, such as "shadow." It was not clear what position the students were referring to with regards to the Moon. Most students never said the position of the Moon relative to something else. Did they mean the position of the Moon in the sky, in its orbit or with respect to the Earth? It is just not possible to tell based on the students' answers. This category does not include any responses that mention the motion of the Moon. Sample student responses are as follows:

> “It changes depending on it’s [sic] relative position to the Sun and Earth - it is full when it is on the opposite side of the Earth as the Sun.”
>
> “depending on where it is in the sky.”
>
> "It is because of it's [sic] position to the Earth."

4.2.8 Reflection of Sunlight and the Motion of the Moon

This category includes responses that involve both the motion of the Moon and the reflection of sunlight. This category is not considered part of the combination category for two specific reasons. Students specifically mentioned both the motion of the Moon and the reflection of sunlight in their responses. These are the only two ideas in the explanations. Students were very clear that lunar phases were caused by only these two things. Second, these responses are nearly right but are missing some final piece, which was different for each student, to make the answer correct. It did not seem reasonable to put these nearly correct answers into a category, for example the *Combination* category, where most of the answers were clearly wrong. Sample student responses are as follows:

> “The Moon rotates around the Sun, and depending what point the Moon is around the Sun will show the brightness. If the Moon is behind the Sun totally, it will be a “full Moon” and vice-versa”
>
> “The Sun reflects off the Moon and as the Moon revolves around the Earth, the same side always faces the Earth. We only see the light parts of the Moon so some sometimes we see all of it, in between or none.”
>
> “Because as the Moon revolves around the Earth we keep seeing it from the same place but the Sun’s light hits it in different areas”

4.2.9 Reflection of Sunlight and the Position of the Moon

Responses in this category specifically mention both the reflection of sunlight and the position of the Moon as the cause of the lunar phases. This is not considered a combination category as the responses stated these two things specifically and not combined with other ideas. Again these responses could be considered partially correct, depending on how they are interpreted. Some responses in this category are clearly wrong while others that may seem correct have the similar phrasing as the ones that are wrong. Sample responses from this category follow:

> "The moon appears full because of the position it is in directly related to that of the sun. The Sun is illumination all of it. It is a crescent shape because the sun is rotating and only part of the moon is illuminated."

> "It's sunlight reflecting off of the moon. How we see it depends on the moon's position in its orbit."

> "The moon sometimes appears as a full bright circle because it is at such a position that the sun's light reflects off all of it. When it is in a crescent shape it is in such a position where the sun's light reflect [sic] off only a portion of it."

4.2.10 Combination

Students in this category responded in such a way that their answers overlapped categories. It seemed as if these students thought there were many causes to the phases of the Moon and weren't sure which one to pick. This category could be the product of students' having fragmentary knowledge and not being able to really separate what they know about the Moon and Earth into a clear explanation for lunar phases. As opposed to the previous categories which only had one or two main ideas in the responses, the answers in this category had at least three or more ideas, or they were composed of different ideas that were not held by many other students such as, for example, that the cause of lunar phases is due to both the motion of the Moon and the tilt of the Moon. Sample student responses are as follows:

> "Because of the way it orbits the Earth, the tilt of the Earth on it's [sic] axis, and the rotation of the Moon. Because of a combo of these things we only

> can see parts of the Moon at one time. The Moon goes through a series of phases in which it increases to a full Moon, then decreases back down."

> "The Moon goes in phases and revolves around the Earth and when the Moon appears to be a full bright circle it is because of the position of the Moon and because of the Sun which determines what phase of the Moon is at."

> "Because of the rotation of the Moon and Earth and the tilt of the Moon."

4.2.11 Other

This category includes responses that did not fit into any other category. Additionally, categories that received less than 5% of the student responses were grouped into this category. The different categories with response rates of less than 5% for Group A1 and A2 are given in Table 13. Some examples of student responses are:

> "Because of the time of year it is, and what season it is."

> "it just depends on what part of the Moon is facing the Earth."

> "Because of the way the phases of the Sun shines on the Earth."

> "I think that it has something to do with cloud cover and where the Sun sets and when it gets below the horizon line."

4.3 Categories of Answers

Student answers could be broken up into ten major categories as listed in Table 9. The addition of a *Blocking* category was unexpected as it had not been seen in previous literature, which usually had around five categories. This research used a large number of categories to get an accurate portrayal of students' ideas.

Group A, which represents all students regardless of the instruction they recieved, has 413 responses for the first survey but only 337 responses for the second survey. The large difference in response rate is more than likely because the second survey was given on the last day of the semester, when many students skipped. Also, some students did drop the class. Group B has 192 students. This group of students took both surveys and received traditional instruction. Group C, the special instruction group, had a total of 69 students.

In some cases, students responded either to the question on lunar phases or to the question on the scale model of the Earth-Moon system, but not to both. In addition, these students' first survey and second survey responses sometimes differed as to which questions were answered. For this reason, in the case of Groups B and C, the first and second survey results do not generally represent exactly the same number of responses as each other, nor do all the different tables representing the same survey for the same group contain the same number of responses. Instead, all responses available for a particular question are represented in the table for that respective group.

Table 9 lists the major categories of student responses as well as the number of students in each category for Group A. The responses for the *Shadow*, *Blocking* and *Other* categories could be divided further and are given in Tables 11, 12, and 13. In the categories *Shadow* and *Blocking*, many students mentioned what was doing the shadowing or the blocking, shown in Tables 11 and 12. The objects that are cause the effect are similar in the two categories.

The *Other* category of Table 9 for Group A, has been broken into smaller categories for Table 13. All of these responses in Table 13 received less than 5% of the total student responses.

Table 10 compares the responses of Groups B and C for both the first and second surveys. This table has an additional category, *Reflection of Sunlight and the Position of the Moon*, included because in these two groups over 5% of student answers could be categorized this way.

4.4 Scale Results

A correctly proportioned scale model of the Earth-Moon system would make the Earth 3.7 times the diameter of the Moon and would place the Moon 30.1 Earth diameters away from each other. In class, students are instructed that these values are 4 and 30, respectively. Now many students could state that fact but when it came to sketching it out, these students were unable to do so. The range of responses considered "correct" for the ratio of Earth diameter to Moon Diameter (E/M) was between 3 and 5, while the "correct" range for ratio of Earth diameter to Earth-Moon distance was considered to be from 20 to 40. Students who wrote out the correct ratios numerically but could not draw the relationship correctly are still being analyzed at this time.

Table 9: Major Categories of Student Responses, Group A1 and A2[a]

Category	A1		A2	
	N	%	*N*	%
Blocking	93	23	44	13
Shadow	84	20	75	22
Correct	42	10	35	10
Reflection of Sunlight	36	9	30	9
Motion of the Earth	24	6	5	1
Combination	21	5	5	1
Reflection of Sunlight and the Motion of the Moon	15	4	25	7
Motion of the Moon	15	4	17	5
Position of the Moon	5	1	32	9
Other	78	19	69	20
Totals	413[b]		337	

[a] Students in this group consist of all students regardless of instruction received and may have answered both surveys or not, but includes data for each survey.

[b] The total from A1 does not match Table 8's total as one student filled out the information requested in Table 8 but did not do a survey.

Table 10: Major Categories of Student Responses, Groups B1, B2, C1, C2

Category	B1[a]		B2[a]		C1[b]		C2[b]	
	N	%	*N*	%	*N*	%	*N*	%
Blocking	33	17	28	15	16	25	6	9
Shadow	43	23	31	17	10	16	20	29
Correct	24	13	16	9	9	14	13	19
Reflection of Sunlight	15	8	13	7	6	9	4	6
Motion of the Earth	10	5	4	2	4	6	0	-
Combination	9	5	4	2	2	3	0	-
Reflection of Sunlight and the Motion of the Moon	9	5	16	9	1	2	3	4
Motion of the Moon	4	2	8	4	3	5	2	3

Position of the Moon	3	2	16	9	0	-	5	7
Reflection of Sunlight and the Position of the Moon	8	4	9	5	1	2	5	7
Other	33	17	31	17	13	20	10	15
Totals	189		182		64		68	

[a] Group B received only traditional instruction. B1 stands for Group B, first survey, B2 for Group B, second survey.

[b] Group C received special instruction. C1 stands for Group C, first survey and C2 is for the second survey of Group C.

Table 11: Breakdown of *Shadow* Category, Group A

Shadow of:	**A1**[a]		**A2**[b]	
	N	*%*	*N*	*%*
Earth	64	76	57	76
Sun	4	5	4	5
Moon	1	1	1	1
Undetermined	15	18	13	17
Totals	84		75	

Note: This data is for all students, both surveys, regardless of instruction received.

[a] A1 is the first survey.

[b] A2 is for second survey.

Table 12: Breakdown of *Blocking Category*, Group A

Blocking done by:	**A1** [a]		**A2** [b]	
	N	%	*N*	%
Earth	54	57	27	61
Sun	15	16	7	16
Planet	5	5	0	-
Moon	1	1	3	7
Undetermined	13	14	7	16
Totals	94		44	

Note: This data is for all students, both surveys, regardless of instruction received.
[a] A1 is the first survey.
[b] A2 is for second survey.

Table 13: Breakdown of *Other* Category, Group A

Category	**A1** [a]		**A2** [b]	
	N	%	*N*	%
Clouds	6	8	1	1
Description of Phases	8	10	11	16
No answer	1	1	4	6
No fit in previous categories	13	17	15	22
Position of Earth	7	9	0	-
Reflection of Sunlight and Position of the Moon	13	17	17	25
Position of the Sun	5	6	0	-
Motion of Earth and Moon	6	8	14	20
Scientific Jargon	12	15	6	9
Time	7	9	1	1
Totals	78		69	

Note: This table is for all students, both surveys, regardless of instruction received.
[a] A1 is the first survey.
[b] A2 is for second survey.

For all tables and figures, E represents the diameter of the Earth, M represents the diameter of the Moon and d represents the distance between the Earth and Moon. E/M is the ratio between the Earth diameter and the Moon diameter and d/E is the distance between the Earth and Moon in Earth diameters.

Students gave a wide variety of responses for the d/E ratio. This made it necessary to group these responses into categories consisting of brad ranges. A student who believes that the Earth and Moon are 3 Earth diameters apart has essentially the same scale conception as a student who believes that they are 4

Earth diameters apart. A student who believes the Earth and Moon are 20 Earth diameters apart has a much different conception than the student who believes that they are 3 Earth diameters apart.

Because some students drew the Moon much larger than the Earth, there needed to be groupings that accounted for those students. Also there were students who drew the Moon much smaller than the Earth, therefore groupings were needed to reflect this. This accounts in part for the choice of categories for the E/M ratio. For the d/E ratio, one of the categories was chosen based on Sadler's research. He suggests that most students believe that the Moon is 3 to 10 Earth diameters away from each other. Based on this, a grouping of responses with a d/E from 3 to 10 was decided to be appropriate. There were some students who believed that the Moon was very far away from the Earth, so the grouping of d/E greater than 40 was needed. Responses that indicated a d/E value less than one were grouped together, and two additional categories (1► d/E<3 and 10► d/E<20) were added to account for the full range of responses

Figures 3 through 8 are histograms that give the frequency of student answers for both Groups A, B and C for both survey. Figures 3, 4, 5 give the frequency of the responses for each Earth/Moon (E/M) diameter ratio. Figures 6, 7, 8 give the frequency of responses for the distance to the Moon in terms of Earth diameter (d/E). In all figures, the first (dark) bar represents the results from the first survey.

The next set of tables, Table 14 through 19 categorize both the students' d/E ratio and E/M ratios. The row and column that is shaded gray are the columns that represent correct student responses for either the d/E or the E/M ratios. The intersection of both gray bars represent where student responses that are correct in for both ratios.

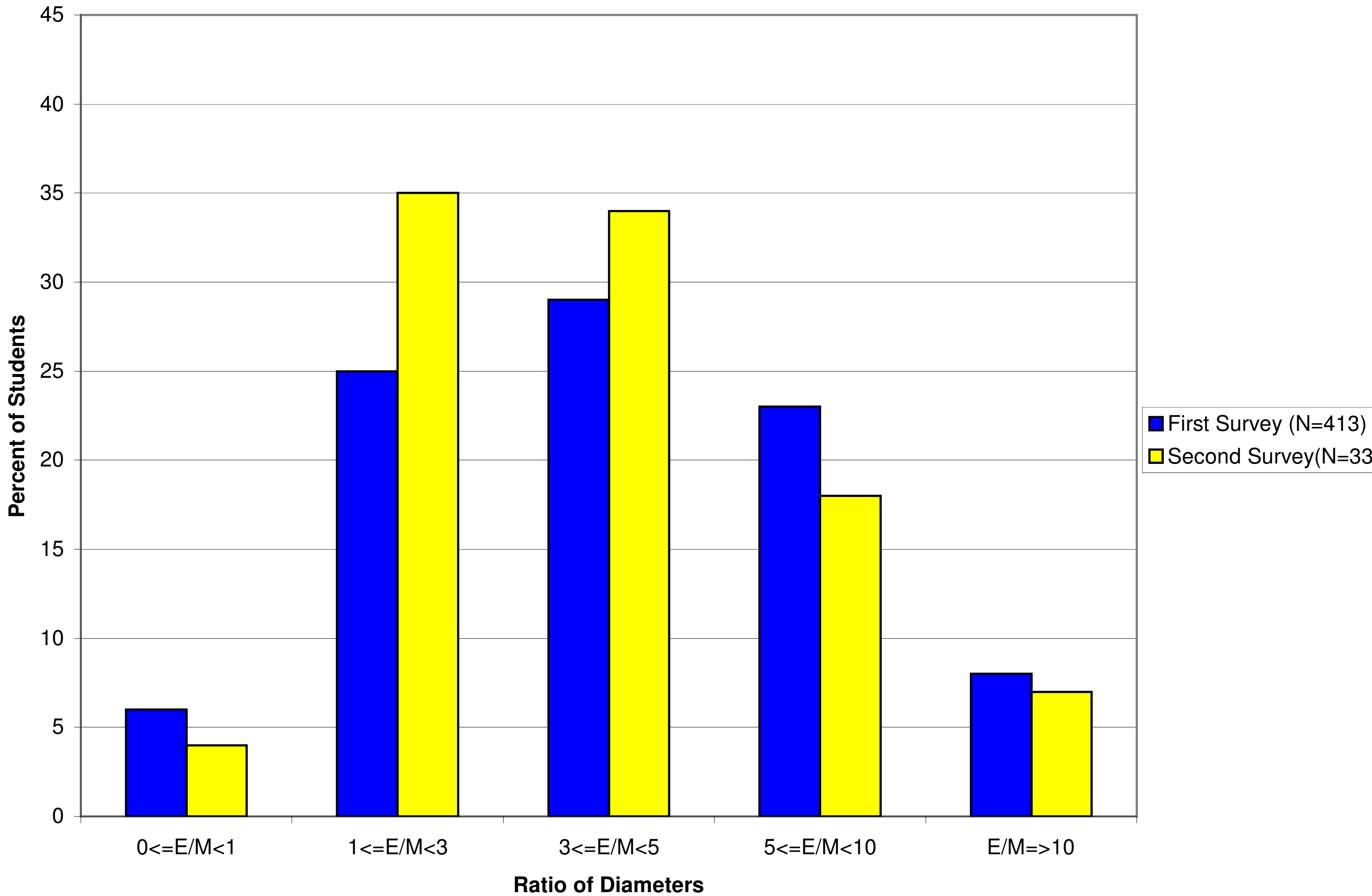


Figure 3. Earth/Moon Diameter, Student Responses, All Categories, All Students

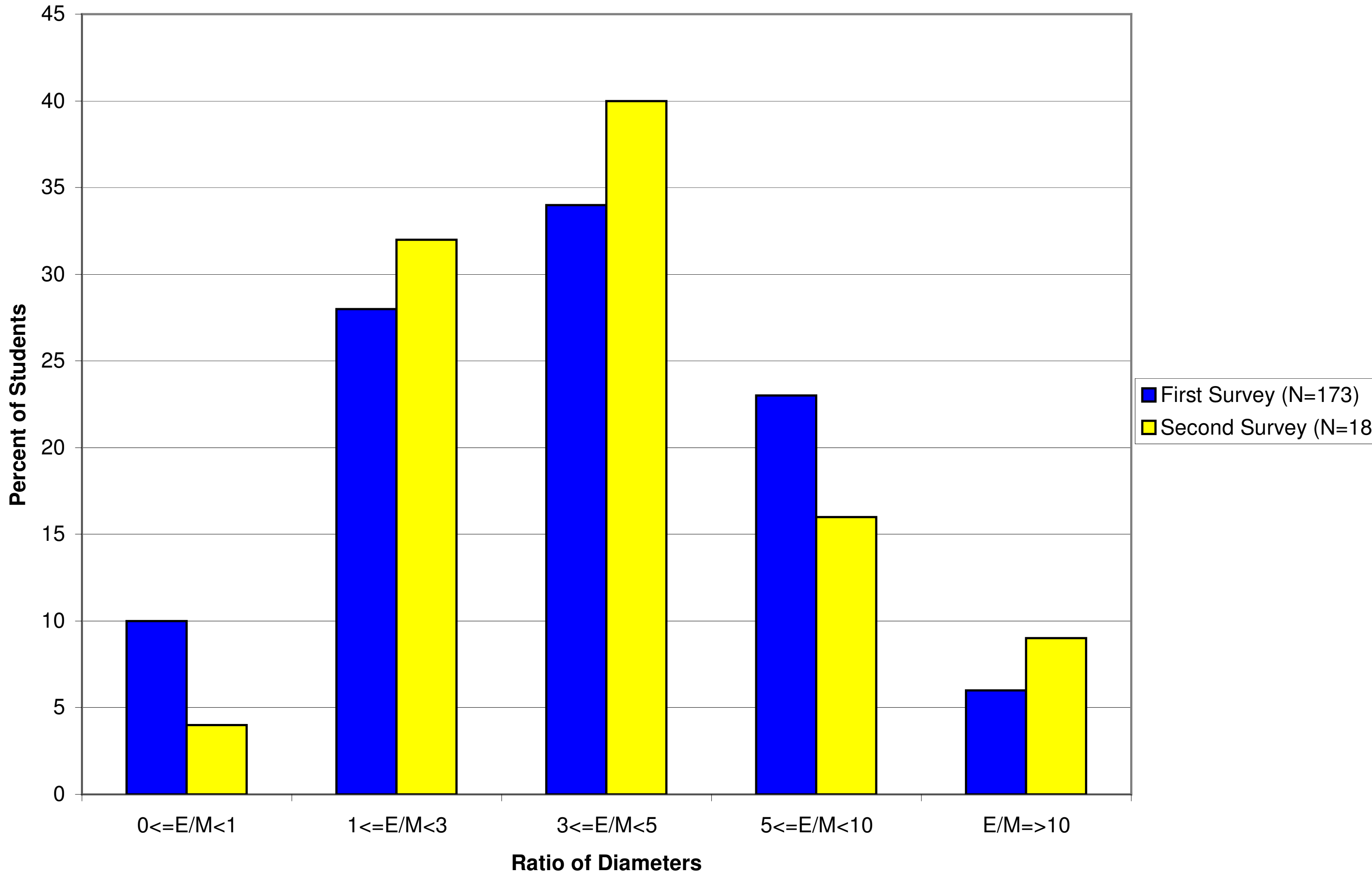


Figure 4. Earth/Moon Diameter, Students Receiving Traditional Instruction, All Categories (B)

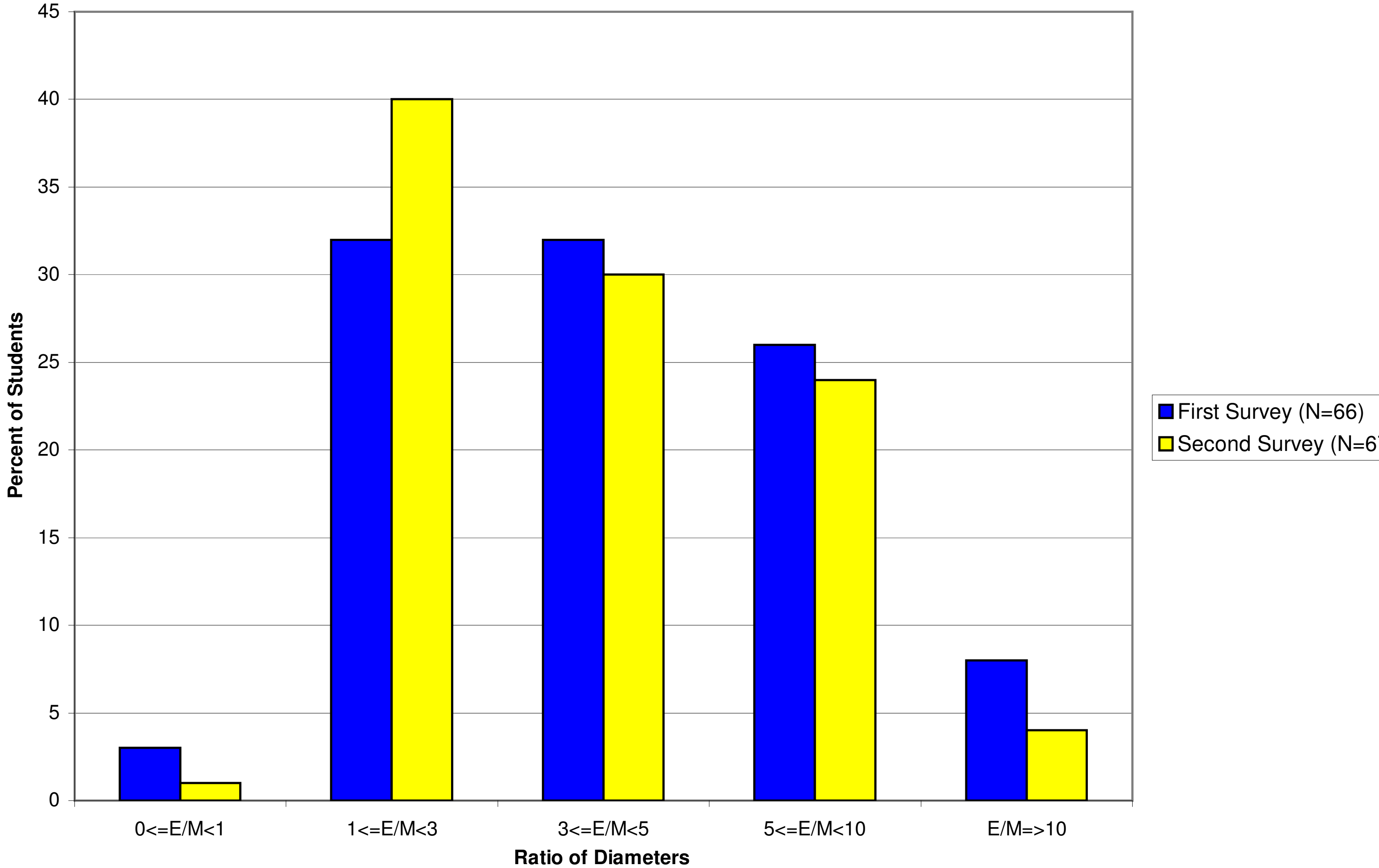


Figure 5. Earth/Moon Diameter, Students Receiving Special Instruction, All Categories (C)

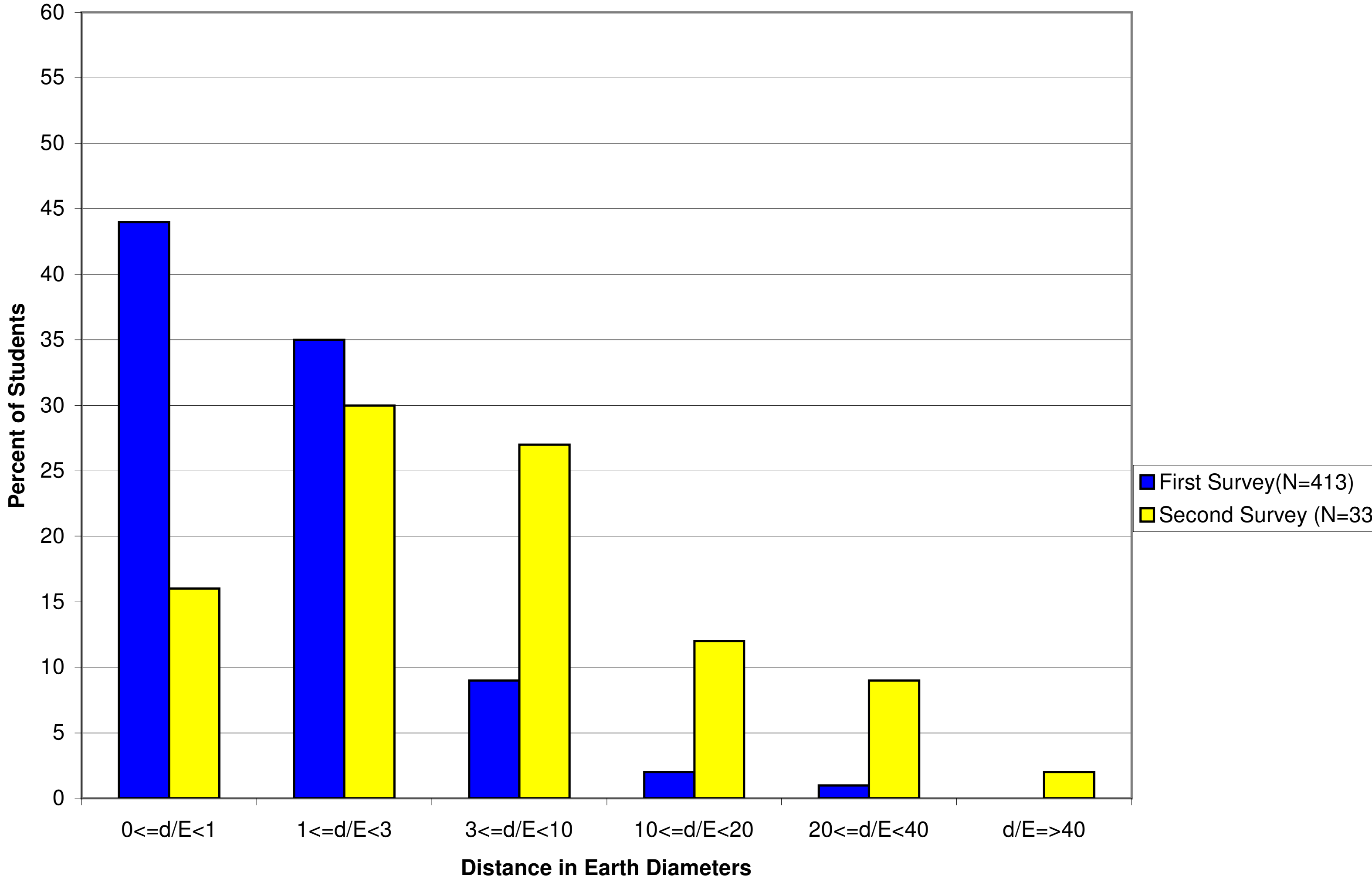


Figure 6. Earth-Moon Diameter (d) in Earth Diameters, Student Responses, All Categories, All Students (A)

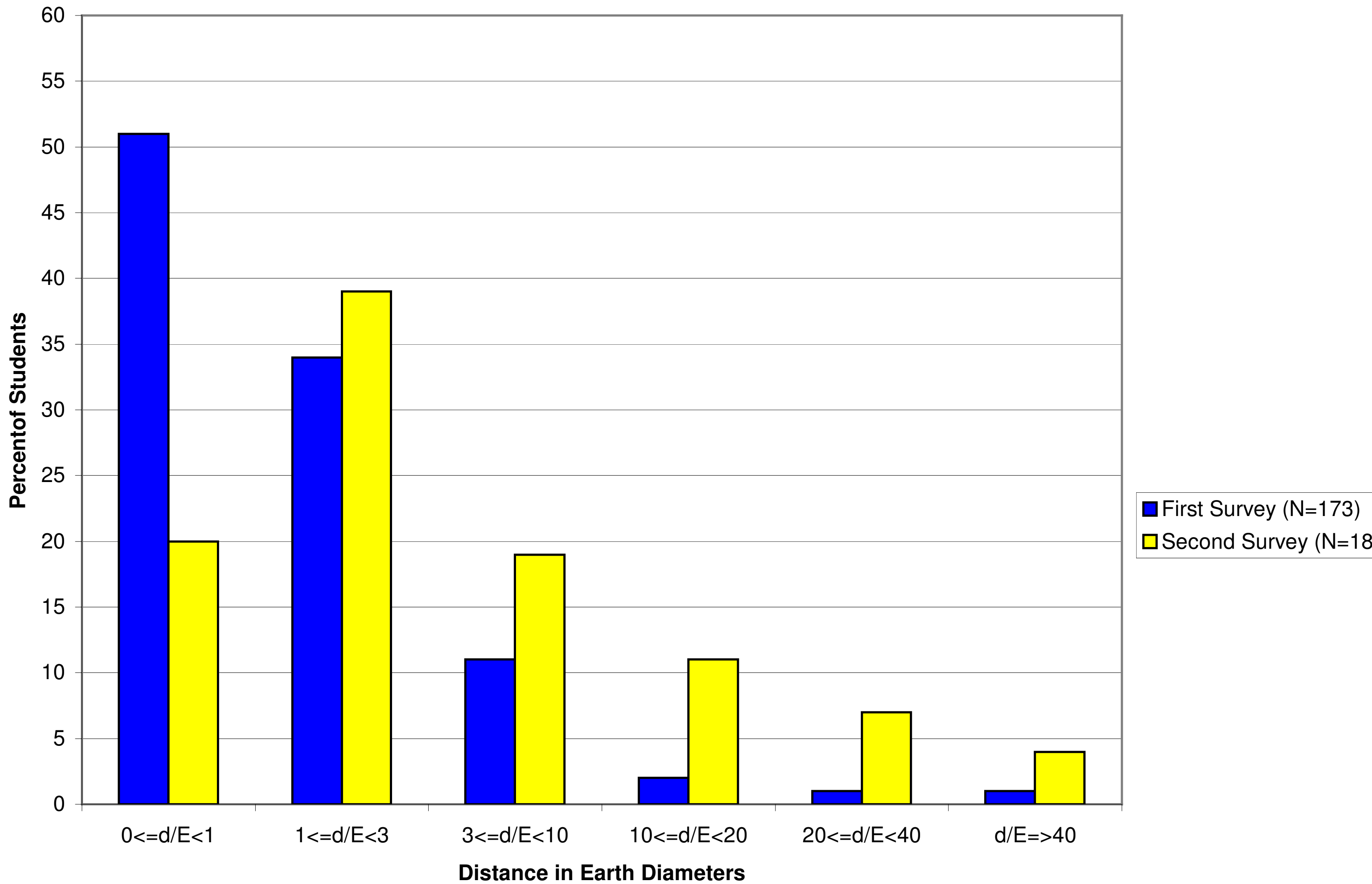


Figure 7. Earth-Moon Distance (d) in Earth Diamters (E), Students Receiving Traditional Instruction, All Categories (B)

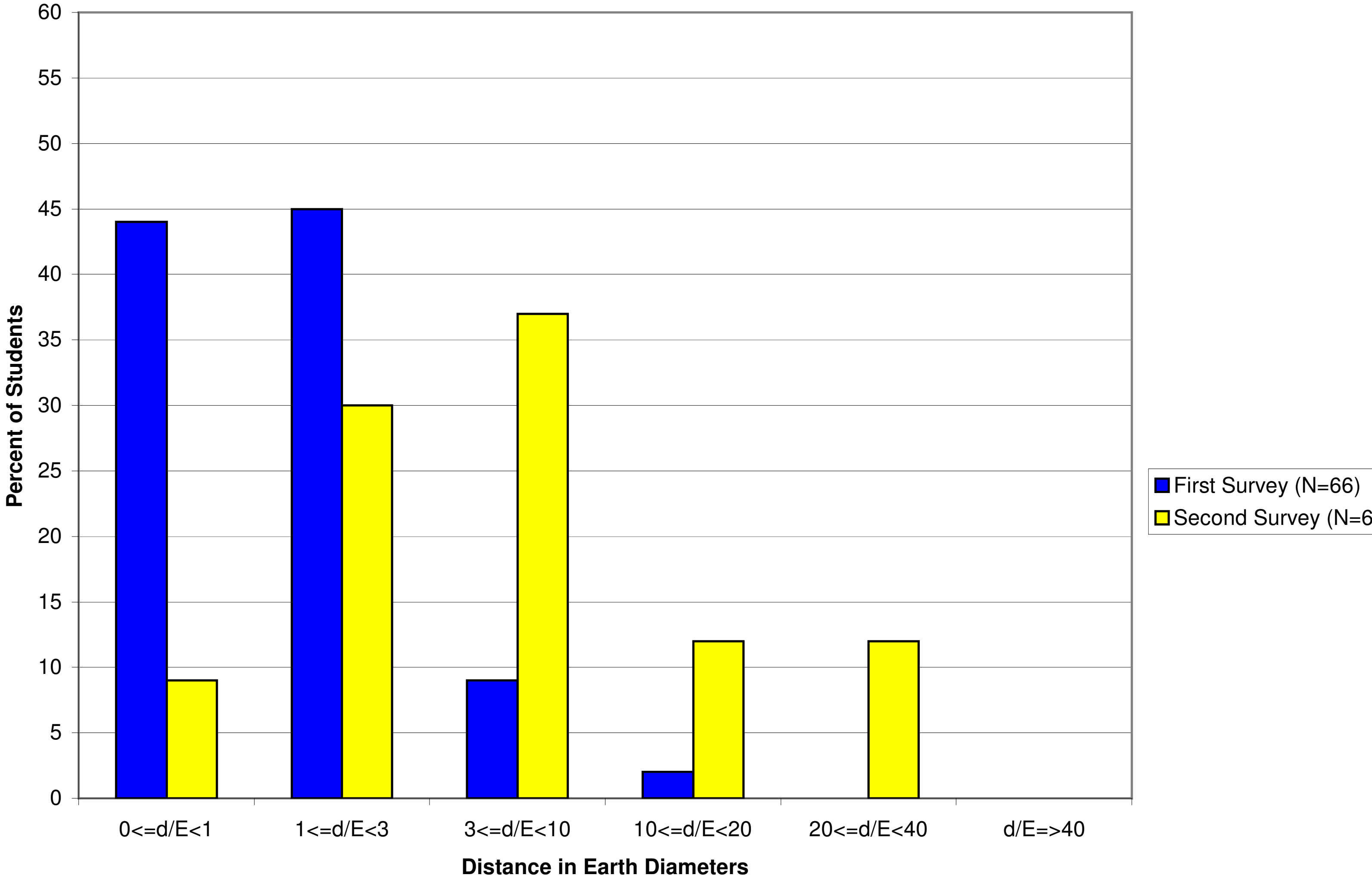


Figure 8. Earth-Moon Distance (d) in Earth Diameters (E), Students Receiving Special Instruction, All Categories (C)

Table 14: Group A1: Student Responses For All Categories, in Percent of Students (*N*=376)

	0<d/E<1	1▶ d/E<3	3▶ d/E<1(	10▶ d/E<20	20▶ d/E<40	d/E ▶ 40	Total
0<E/M<1	0	3	3	0	-	-	7
1▶ E/M<3	12	13	2	1	0	0	28
3▶ E/M<5	15	13	3	1	1	0	32
5▶ E/M<10	16	7	2	0	-	-	25
E/M ▶ 10	5	2	1	-	-	-	8
Total	48	38	10	2	1	1	

Note: 37 students did not provide answers. This table includes all students who took the first survey.

Table 15: Group A2: Student Responses For All Categories, in Percent of Students (*N*=325)

	0<d/E<1	1▶ d/E<3	3▶ d/E<10	10▶ d/E<20	20▶ d/E<40	d/E ▶ 40	Total
0<E/M<1	0	1	2	0	0	1	4
1▶ E/M<3	5	13	10	2	4	1	36
3▶ E/M<5	6	9	10	5	4	1	35
5▶ E/M<1(	3	6	4	4	1	-	18
E/M ▶ 1(	2	3	2	1	-	-	7
Total	16	31	16	13	9	2	

Note: 12 students did not provide answers. This table includes all students who took the second survey.

Table 16: Group B1: Student Responses for All Categories, in Percent of Students (N=173)

	0<d/E<1	1▶ d/E<3	3▶ d/E<10	10▶ d/E<20	20▶ d/E<40	d/E ▶ 40	Total
0<E/M<1	1	5	3	1	-	-	10
1▶ E/M<3	13	12	1	1	-	-	28
3▶ E/M<5	17	11	5	-	1	1	34
5▶ E/M<10	16	5	2	-	-	-	23
E/M ▶ 10	4	2	-	-	-	-	6
Total	51	34	11	2	1	1	

Note: 19 students did not provide answers. This table shows the results of the first survey of students who took both surveys and received traditional instruction.

Table 17: Group B2: Student Responses For All Categories, in Percent of Students (N=187)

	0<d/E<1	1▶ d/E<3	3▶ d/E<10	10▶ d/E<20	20▶ d/E<40	d/E ▶ 40	Total
0<E/M<1	1	1	1	-	1	1	4
1▶ E/M<3	4	16	5	3	3	2	32
3▶ E/M<5	10	12	7	5	4	1	40
5▶ E/M<1(	4	6	4	2	-	-	16
E/M ▶ 1(	2	4	2	1	-	-	9
Total	20	39	19	11	7	4	

Note: 5 students did not provide answers. This table shows the results of the second survey of students who took both surveys and received traditional instruction.

Table 18: Group C1: Student Responses For All Categories, in Percent of Students (N=66)

	0<d/E<1	1▶ d/E<3	3▶ d/E<10	10▶ d/E<20	20▶ d/E<40	d/E ▶ 40	Total
0<E/M<1	-	2	2	-	-	-	3
1▶ E/M<3	15	15	2	-	-	-	32
3▶ E/M<5	9	18	5	-	-	-	32
5▶ E/M<10	15	8	2	2	-	-	26
E/M ▶ 10	5	3	-	-	-	-	8
Total	44	45	9	2	-	-	

Note: 3 students did not provide answers. This table shows the results of the first survey for students who received special instruction and answered both surveys.

Table 19: Group C2: Student Responses For All Categories in Percent of Students (N=67)

	0<d/E<1	1▶ d/E<3	3▶ d/E<10	10▶ d/E<20	20▶ d/E<40	d/E ▶ 40	Total
0<E/M<1	-	-	1	-	-	-	1
1▶ E/M<3	4	15	10	-	7	-	40
3▶ E/M<5	-	4	18	3	3	-	30
5▶ E/M<1(	3	9	6	4	1	-	24
E/M ▶ 1(	1	1	1	4	-	-	4
Total	9	30	37	12	12	-	

Note: 2 students did not provide answers. This table shows the results of the second survey for students who received special instruction and answered both surveys.

4.5 Scale and Category Results

The purpose of this research was to see if scale had an impact on student ideas regarding lunar phases. To try and see if there was indeed a connection, grids similar to the previous tables were made for each category listed in Table 9 for both Group A1 and A2. These additional grids are located in Appendix E.

Tables 20 through 25 show the relationship between four of the categories listed in Table 9 and the d/E ratio indicated on the student's responses to the scale question. The *All Other* category consists of all categories except for *Correct*, *Shadow* and *Blocking*. The first N column, All Categories, is for all categories and the percent value in the next column is percent of the total number of students. For each of the category percentages (i.e., those under *Correct, Shadow, Blocking* and *All Other*) the numbers represent the proportion of each ratio category (e.g., $0<d/E<1$) that fell in the respective category from Table 9 (e.g., *Correct* or *Blocking*).

In general, the percentage of students who believe that the lunar phases are caused by something other than blocking, shadow or the correct reason increase between surveys. Except for Group C, the special instruction group, the percentage of students answering correctly decreases between surveys. When looking at the d/E rows, initially students think that the Earth and Moon are very close. After instruction, students still think that the Earth and Moon are close, but there answers start to move the Earth and Moon farther apart.

Is there a connection between students' scale models and their lunar phase explanation? Chapter 5 takes an in-depth look at this topic.

4.6 Moon Concept Inventory Results

At the time of the writing of this thesis, the Moon Concept Inventory results have not yet been completely analyzed, but there are a few preliminary results of relevance to this study. Question 19 asked "*What caused the Moon to change its shape in Question 18?*" Out of the 403 students who answered this question, 7% choose option A, "an object is no longer between the Moon and the Earth." 22% choose option B, "the Moon is no longer covered by the shadow of the Sun," while 55% choose option C, "the Moon is no longer covered by the shadow of the Earth."

The last option, "None of the above," is chosen by 15% of the students. This question did not have the correct answer explicitly stated as an option. Therefore, the percentage of students who chose the correct answer was higher in her research than what is reported here. However, assuming that the students whose conceptions were classified as incorrect mainly because they were incomplete would be likely to choose the correct answer, then the numbers in both studies become about the same. There is a striking difference between the number of students who choose option B, "The Moon is no longer covered by the shadow of the Sun," on her instrument and those giving this as an explanation in our open-ended survey. Only 1% of students wrote this explanation on the first survey, while 22% chose option B on the Moon Concept Inventory. Over half of the students answering this question on the Moon Concept Inventory selected the cause of the lunar phases as the shadow of the Earth, while on the free response question used in this research, roughly 20-23% of students taking the first survey explained the cause of the lunar phases as the shadow of the Earth. This result is particularly noteworthy because it demonstrates that the very same group of students may give very different responses to apparently similar questions posed just a few minutes apart, when those questions are presented in different formats as was done here.

Table 20: Group A1: Distance vs. Category for All Students Taking the First Survey (*N*=376)

d/E	**All Categories**		**Correct**		**Shadow**		**Blocking**		**All Other**[a]	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
0<d/E<1	182	48	20	11	44	17	38	21	80	44
1► d/E<3	143	38	12	8	22	15	34	24	75	52
3► d/E<10	38	10	5	13	10	26	9	24	14	37
10► d/E<20	8	2	2	25	2	25	1	13	3	38
20► d/E<40	3	1	2	67	0	-	0	-	1	33
d/E ► 40	2	1	0	-	1	50	0	-	1	50
Total	376		41	11	79	21	82	22	174	46

[a] *Other* Category is all categories other than *Shadow, Blocking or Correct*.

Table 21: Group A2: Distance vs. Category for All Students Taking the Second Survey (*N*=325)

d/E	All Categories		Correct		Shadow		Blocking		All Other[a]	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
0<d/E<1	53	16	5	9	11	21	10	19	27	51
1▶ d/E<3	101	31	5	5	24	24	19	19	53	52
3▶ d/E<10	92	28	8	9	21	23	5	5	58	63
10▶ d/E<20	41	13	8	20	8	20	5	12	20	49
20▶ d/E<40	30	9	7	23	9	30	3	10	11	37
d/E ▶ 40	8	2	1	13	1	13	2	25	4	50
Total	325		34	9	74	23	44	14	173	53

[a] *Other* Category is all categories other than *Shadow, Blocking or Correct*.

Table 22: Group B1: Distance vs. Category Results for the First Survey of Students Receiving Traditional Instruction Taking Both Surveys. (*N*=173)

d/E	All Categories		Correct		Shadow		Blocking		All Other[a]	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
0<d/E<1	89	51	13	15	23	26	13	15	40	45
1▶ d/E<3	59	34	4	7	12	20	12	20	31	53
3▶ d/E<10	19	11	3	16	4	21	5	26	7	37
10▶ d/E<20	3	2	0	-	1	33	0	-	2	66
20▶ d/E<40	2	1	1	50	0	-	0	-	1	50
d/E ▶ 40	1	1	0	-	1	100	0	-	0	-
Total	173		21	12	41	24	30	17	81	47

[a] *Other* Category is all categories other than *Shadow, Blocking or Correct*.

Table 23: Group B2: Distance vs. Category Results for the Second Survey of Students Receiving Traditional Instruction Taking Both Surveys. (*N*=181)

d/E	All Categories		Correct		Shadow		Blocking		All Other[a]	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
0<d/E<1	37	20	1	3	11	30	8	22	17	46
1▶ d/E<3	66	36	3	5	11	17	13	20	39	59
3▶ d/E<10	38	21	4	11	5	13	1	3	28	74
10▶ d/E<20	20	11	3	15	2	10	2	10	13	65
20▶ d/E<40	14	8	3	21	3	21	2	14	6	43
d/E ▶ 40	6	3	1	17	1	17	0	-	4	67
Total	181		15	8	33	18	26	14	107	59

[a] *Other* Category is all categories other than *Shadow*, *Blocking* or *Correct*.

Table 24: Group C1: Distance vs. Category Results for the First Survey of Students Receiving Special Instruction Taking Both Surveys. (*N*=64)

d/E	**All Categories**		**Correct**		**Shadow**		**Blocking**		**All Other** [a]	
	N	*%*	*N*	*%*	*N*	*%*	*N*	*%*	*N*	*%*
0<d/E<1	27	42	3	11	3	11	9	33	12	44
1▶ d/E<3	30	47	3	10	6	20	5	17	16	53
3▶ d/E<10	6	9	2	33	1	17	2	33	1	17
10▶ d/E<20	1	2	1	100	0	-	0	-	0	-
20▶ d/E<40	0	-	0	-	0	-	0	-	0	-
d/E ▶ 40	0	-	0	-	0	-	0	-	0	-
Total	64		9	14	10	16	16	25	29	45

[a] *Other* Category is all categories other than *Shadow*, *Blocking* or *Correct*.

Table 25: Group C2: Distance vs. Category Results for the Second Survey of Students Receiving Special Instruction Taking Both Surveys. (*N*=66)

d/E	**All Categories**		**Correct**		**Shadow**		**Blocking**		**All Other** [a]	
	N	*%*	*N*	*%*	*N*	*%*	*N*	*%*	*N*	*%*
0<d/E<1	7	11	3	43	1	14	0	-	3	43
1▶ d/E<3	19	29	2	11	6	32	3	16	8	42
3▶ d/E<10	24	36	3	13	8	33	2	8	11	46
10▶ d/E<20	8	12	3	38	2	25	1	13	2	25
20▶ d/E<40	8	12	2	25	3	38	0	-	3	38
d/E ▶ 40	0	-	0	-	0	-	0	-	0	-
Total	66		13	20	20	31	6	9	27	41

[a] *Other* Category is all categories other than *Shadow, Blocking* or *Correct.*

CHAPTER 5: DISCUSSION OF RESULTS

Previous research at the college level has used multiple choice tests designed to discover student misconceptions before and after instruction. When given these tests, students are faced with only four or five choices which may or may not reflect their conceptions on the subject. A diagnostic allowing students to answer freely is needed to discover what they really think. Along with identifying misconceptions, previous research has looked into possible connections a misconception may have with other things, such as spatial abilities.

One of the most difficult concepts in a college level astronomy class is the cause of the Moon's phases. Much prior research has focused on this topic, describing the different problems and the lack success of students have with this topic. Researchers have looked at the students' ability to understand this concept based on their spatial ability and based on different methods of instruction.

This research project differed from other reported in the literature in part by an open-ended question; students were not given choices and therefore were unable to guess at the answer. By examining the causes of the lunar phases and the scale of the Earth-Moon system together, the researcher tried to determine whether or not there was connection between them. Up until this point, no research has looked at lunar phase misconceptions in conjunction with scale.

In designing this research, it was hoped that a definite connection between the cause of the lunar phase and scale and that if specific attention is placed on scale in connection with the lunar phases, student conception will become more correct.

5.1 Discussion of Category Results

Student responses for both surveys were classified into 23 groups with 10 being the most significant categories. Tables 9 and 10 in Chapter 4 show the change in student conceptions of the causes of the lunar phases for both surveys of different groups of students. Table 9 shows the results of all of the students. For Group A, the percent of students able to give the correct explanation of the cause of the lunar phases is the same for both surveys. Additionally, the proportion of students who believe shadows cause the lunar phases stays the same. Most categories show a percentage decrease between the first and second surveys. However, categories that are fragments of the correct model, such as *Reflection of the Sunlight and the Motion of the Moon*, see an increase. It appears that any instruction on lunar phases can help students' conceptions move closer to the correct explanation.

Table 10 shows the results for Groups B and C. Group B students took both surveys and received traditional instruction while Group C students received special instruction. For Group B, there is no change or a decrease in the percent of students between surveys for all of the categories except for three categories. In Group C, the *Correct* category stays statistically the same, but the *Shadow* category shows a significant increase. There is a significant drop in *Blocking* responses for this group. Categories that are fragments of the correct model see an increase in the percent of students between the first and second survey as well.

It was hoped that students receiving special instruction, Group C, would be better able to explain the causes of the lunar phases correctly than students receiving only traditional instruction, Group B. Before instruction the same percent of students in both groups were able to correctly explain the causes of the lunar phases. After instruction, 9% of students in Group B gave the correct explanation, while in Group C, 19% were able to give the correct cause of the lunar phases. When looking at the *Blocking* category, there is a decrease in responses between Group B and C, with Group C being smaller. For Groups B and C, there is a difference in the *Shadow* category. Group C has a much larger response rate, 29%, than Group B with 17%. Unfortunately, it appears that special instruction did very little to change student conceptions of the lunar phases to the correct conception. The difference in the correct response rate between Groups B and C was not as large as hoped, although there was a small change. What was most disturbing was the large increase in the *Shadow* category between the two groups. During the special instruction, students were asked to point out the shadows many times. Perhaps mentioning shadow in the lesson caused this word/explanation to stick in the students' minds. What this probably means is that words such as shadow and blocking have to be used very carefully with students so that they do not pick up the idea that is being disproved.

There are increases in student responses in categories that are nearly correct or that are fragments of the correct model. This is promising because it means that students are hearing the correct explanation and may be incorporating this new information into their conceptions. If the categories were regrouped into *Correct*, *Nearly Correct*, and *Not Correct*, there might be a significant difference between groups of students which would be more illustrative of student ideas.

5.2 Discussion of Scale Results

In the discussion on scale, first the size scale and distance scale will be discussed separately and then the relationship between them will be discussed. Figures 3 through 8 in Chapter 4 are histograms for each of the groups for both surveys for either the size scale or the distance scale. Tables 14 through 19 in Chapter 4 are tables showing both the size and the distance for each group and each survey.

Figure 3 charts the student responses for the diameter of the Earth divided by the diameter of the Moon (E/M) for both surveys of Group A. The responses for the first survey (dark/blue column) form a Gaussian with the peak of around 28% of the students between 3 and 5 E/M diameters. For the second survey (light/yellow column) of Group A, more students give the correct ratio and other students have changed their scale sizes from really big or really small to answers that are closer to correct.

For Group B in Figure 4, the results from the first survey are essentially the same as Group A's first survey, although a few more students gave the correct size and nearly twice as many students thought the Earth and Moon were roughly the same size or that the Moon was bigger. For the second survey of Group B, the proportion of students who believed that the E/M was less than one dropped by over half. 40% of students on the second survey in this group were able to get the correct ratio, an increase of 6% over the first survey. Comparing the second surveys of Groups A and B for the correct ratio, Group B has a 6% increase over the second survey in Group A. For Group B there was a slight increase in student responses that had the Moon much, much smaller than the Earth, E/M greater than 10, which is unexpected because both Group A and C showed decreases in this size range.

Figure 5 shows the scale size results for both surveys of Group C. There were decreases from the first survey in responses that were very wrong, the size being too small or too big, but there was not a large change in the percentage of students giving the correct size ratio. There was a 2% drop in correct responses between the first and second surveys. For the first survey, the proportion of responses that showed E/M in the 1 to 3 range was the same as those in the 3 to 5 range. On the second survey, 40% of students put E/M in the 1 to 3 range, while 30% had it in the 3 to 5 rang. Students in Group C who had very distorted pictures of the size of the Earth and Moon developed a more realistic picture after instruction. Comparing Group B to Group C, more students in Group B, 10% more, were able to give the correct relative size of the Earth and Moon on the second survey. Looking at the results of the second survey for the grouping between 1 and 3, Group C has 6% more students than Group B. It is disturbing that the group receiving special instruction on scale, Group C, did not do as well on the scale size as did Group B, who received no special instruction on scale. Students in Group C did do better than students in Group A for all ranges of E/M values.

Figures 6, 7 and 8 in Chapter 4 chart the percentage of students in each group for both surveys at a particular Earth-Moon distance in Earth diameters. Figure 6 is for both surveys of Group A. Students in Group A start off with the Earth and Moon very close, with over 75% responding that the Earth and Moon are less than 3 Earth diameters apart. 44% believe that the Earth and Moon are with 1 Earth diameter of each other. This is slightly distressing because it leads to another question of students, "Can we fly to the Moon on a airplane?" If the students truly believe that the Earth and Moon are this close, what would the students' reasons be if they say it is not possible? It can't be because of the distance because airplanes are capable of circling the Earth. For the second survey of Group A, the students start moving the Earth and Moon farther apart, but 46% students still think that the Earth and Moon are within 3 Earth diameters. Looking at the distances between 3 and 10 Earth diameters, 9% of students thought that the Earth and Moon were this far apart for the first survey. This number jumps to 27% for the second survey. For the distance scale, an answer between 20 and 40 Earth diameters was considered correct. The first survey of Group A, only 1% of students answered correctly. For the second survey of Group A, the percentage of students answering correctly jumps to 9%, an increase of 8%.

Figure 7 using Group B, is very similar to Figure 6 using Group A. 85% of students on the first survey in Group B answered that the Earth and Moon are less than 3 Earth diameters apart. For the second survey this percentage drops to 59% but that is still a large group of students. There is a big change when looking at who believes the distance between the Earth and the Moon as less than 1 Earth diameter. For the first survey, 51% Group B students thought that the Earth and Moon were less than 1 Earth diameter apart, while for the second survey, that percentage drops to 20%, a decrease of 31%. Even after traditional instruction students still hold onto the idea that the Earth and Moon are close to each other. Only 1% of students in the first survey were able to put the Earth and Moon the correct distance apart, somewhere between 20 and 40 Earth diameters. This percent changes to 7% for the second survey, giving only a 5% change. The change between first and second surveys for Group A was 8%. Traditional instruction does seem to help the students start to move the Earth and Moon farther apart, but fails to help students move them far enough away.

Looking at Figure 8 for Group C, the results of the first survey for the distances less than 3 Earth diameters are roughly the same as for Group A and B. Again, comparing the first and second surveys of Group C, there is a large shift towards more correct distance scales. For the correct scale distance, there were no students who choose that distance as correct on the first survey. 12% of students on the second survey were able to place the Earth and Moon the correct distance apart. This is the largest increase between first and second surveys for the three groups of students. Comparing this result in Group C to the same result in Group B, there is an increase in correct response by 7% between groups. The largest change in between both surveys in Group C is the range of distances from 3 to 10 Earth diameters. For the first survey, 9% of students responded in this range while on the second survey 37% placed the Earth and Moon somewhere between 3 and 10 Earth diameters which is a very large increase, the largest out of all three surveys. The special instruction seems to be more effective at moving the Earth and Moon farther apart in student conceptions.

If the ranges of distances are regrouped from 6 ranges to 3 ranges, what will that do to the results? If the correct answer is said to be a distance greater than 10 Earth diameters, will more students be able to give the correct distance? Table 26 and 27 regroups the distances for Groups A, B and C. Looking at Table 26, all three groups of students are essentially the same for the first survey. The groups differ in Table 27. Although the percentage of students placing the Earth and Moon farther than 10 Earth diameters apart for the second survey stays the same for all groups, the proportion of responses in the range of distances between 3 and 10 Earth diameters does vary between the groups. 37% of students in Group C placed the Earth and Moon in this distance range, compared to 19% in Group B, a difference of 18%. There is a 9% difference between Group A and Group C. At first glance, the special instruction appears to be minimally effective in changing student Earth-Moon distance conceptions to the correct distance conceptions. However, special instruction was very effective when looking at getting students to simply increase the Earth-Moon distance from something very close to something much farther away. More instruction on scale at different times during the semester may help students move their distance conceptions to more correct distances.

Tables 14 through 19 in Chapter 4 show size and distance on the same table for each group's survey. Grey lines in each table represent the column and row that

Table 26. Earth-Moon Distance in Earth Diameters for All Groups, First Survey.

d/E	A1[a]		B1[b]		C1[c]	
	N	%[d]	N	%[d]	N	%[d]
0<d/E<3	325	86	148	86	59	89
3► d/E<10	38	10	19	11	6	9
d/E ► 10	13	3	6	3	1	2

Total	376		173		66	

[a] A1- all students in survey
[b] B1- students receiving traditional instruction
[c] C1- students receiving special instruction
[d] percentage of total number of responses in that group whose d/E value fell in the range indicated in the first column

Table 27. Earth-Moon Distance in Diameters for All Groups, Second Survey

d/E	A2 [a]		B2 [b]		C2 [c]	
	N	% [d]	N	% [d]	N	% [d]
0<d/E<3	154	47	110	59	26	39
3► d/E<10	92	28	35	19	25	37
d/E ► 10	79	24	42	22	16	24
Total	325		187		67	

[a] A2- all students in survey
[b] B2- students receiving traditional instruction
[c] C2- students receiving special instruction
[d] percentage of total number of responses in that group whose d/E value fell in the range indicated in the first column

are correct answers. The percent of students who get both size and distance correct is very small. For Group A and B, 1% of students in each group on the first survey and 4%in each group of students on the second survey were able to correctly scale the Earth-Moon system. For Group C, no students were able to get the scale of the Earth-Moon system correct on the first survey and only 3% of students were able to get it right on the second survey. Essentially no students were able to get both the size and distance of the Earth and Moon correct regardless of instruction.

Looking at the percentages of students who were able to come up with the correct scale model is not very insightful since there are so few of them. Instead, you need to look at the general trends or movement of the answers in these tables. For the first survey for all groups, the students tend to be clustered in the first 4 boxes in the table. These students believe that the Earth and Moon are similar in size and very close together. Looking at the second survey, the student responses start moving down and to the right in the tables. Students begin to get a more realistic view of the scale of the Earth-Moon system. Their view of the scale of the Earth-Moon system is still not correct, but is getting closer to it.

5.3 Discussion of Category and Scale Results

The purpose of this research was to see if there was a connection between students' ideas of what causes the lunar phases and their ideas on the scale of the Earth-Moon system. Before the research began, the hypothesis was that students who believed the lunar phases were caused by shadows would be more likely to have a skewed scale of the Earth-Moon system, namely making the Earth and Moon roughly the same size and placing them close together. Tables 20 through 25 in Chapter 4 show on the same table for each group's surveys, the distance between the Earth and the Moon versus the category of explanation of the lunar phases.

Will students who have the correct explanation of the lunar phases have the correct scale model of the Earth-Moon system? Examination of Tables 20 through 25 should help establish a connection if there is one. For all the students taking the first survey, A1, only 2 students who had had the correct scale model were able to explain the causes of the lunar phases correctly. This decrease to 23% of students having the correct scale model being able to correctly explain the causes of the lunar phases on the second survey. Although in the second survey of Group A, more students, 7 versus 2, were able to give the correct explanation, more students overall were able to give the correct scale distance. For students in Group B, the students who received only traditional instruction, one student having the correct scale distance was able to correctly identify the causes of the lunar phases on the first survey. For the second survey of Group B, only one student was able to correctly identify the cause of the lunar phases and give the correct scale distance. Is there a difference for students in Group C, who received special instruction? Yes, there is an increase from no students having the correct scale distance and correct explanation to two students who had the correct scale distance having the correct explanation as well. There appears to be a very slight relationship between getting the correct scale distance and the correct explanation but will larger percentages students who have totally incorrect explanations of the lunar phases be able to correctly scale the distance between the Earth and the Moon?

For the *Shadow* category, do more students in this category think the Earth and Moon are closer or will they have the Earth and Moon the correct distance apart? For the first survey of Group A, no students in the *Shadow* category had the correct distance, but in the second survey, nine students who had the correct Earth-Moon distance believed the lunar phases were caused by shadows. For Group B, no students had the correct distance in the first survey, but in the second survey, three students who had the correct Earth-Moon distance believed the lunar phases were caused by shadows. This is the essentially the same results for Group C. Again, no student in the *Shadow* category was able to place the Earth and Moon the correct distance apart for the first survey. In the second survey, three students who had the correct Earth-Moon distance were in the *Shadow* category. There may be a connection between scale of the Earth-Moon system and lunar phase explanation before instruction, but there does not seem to be one after instruction. However, the sample sizes are too small to make any statistically significant correlation.

For the *Blocking* category, no student in any of the groups was able to give both the correct scale and the correct explanation of the lunar phases on the first survey. Again, there is a percentage increase of students getting the correct scale in the *Blocking* category in Groups A and B on the second survey. However, for Group C, no students in the Blocking category placed the Earth and Moon the correct distance apart. For the special instruction group, C, it does seem that students who have the blocking explanation will not have the correct scale of the Earth-Moon system. Instruction did not alter this view for this group.

As for the *All Other* category, the results are similar to those of the *Shadow* category. For each groups' set of surveys, there is an increase between the first and second survey in the correct scale range, regardless of instruction received. There appears to be no connection to scale models for students who are in the *All Other* category of explaining the lunar phases.

If the groupings of the range of distances were changed while keeping the same categories, would that show a connection with lunar phase explanation? Tables 28 and 29 show different distance groupings versus category for Groups B and C. Students receiving traditional instruction, Group B, and think that the lunar phases are caused by shadows and blocking are over-represented in the range of distances less than 3 Earth diameters. Students receiving special instruction, Group C, who have the correct explanation for the lunar phases, are over-represented in the range of distances greater than 10 Earth diameters. Unfortunately, the percentage of students in Group C who have both the correct explanation and the correct scale distance is equal to the percentage of students who think that the lunar phases are caused by shadows, yet have the correct scale distance. There is also an over-representation of students with distances less than 3 Earth diameters who think the lunar phases are caused by shadows and blocking.

Basically, this research did not show a significant connection between students' explanation of lunar phases and their scale models of the Earth-Moon system. Whether this is true for all student groups is not clear at this time. Maybe with a larger sample of students, a connection can be found. Also, there may be a flaw in the survey instrument itself or in the special instruction. Classification of the surveys was very difficult and the answers may not have been interpreted the way the students intended them to be interpreted. Clearer guidelines for the sorting of the surveys may be needed or a different instrument altogether. For example, the first question on the survey could remain the same while listed on another sheet would be explanations gathered from this research. The student would then be directed to choose all the explanations that belong in a correct answer of the cause of the lunar phases. This would give the researcher two independent answers to help classify the data. Another reason why this research did not work as planned may have been a flaw in the special instruction. During special instruction, students

Table 28: Category Breakdown According to d/E Group for Group B [a]

	Group B- First Survey (*N*=173)					Group B- Second Survey (*N*=181)				
d/E [b]	*N* [c]	% [d] Correct	% [e] Shadow	% [f] Blocking	% [g] All Other	*N* [c]	% [d] Correct	% [e] Shadow	% [f] Blocking	% [g] All Othe
0<d/E<3	148	11	24	17	48	103	4	21	20	54
3► d/E<10	19	16	21	26	37	38	11	13	3	74
d/E ► 10	6	17	33	-	50	40	18	15	10	58

[a] Group B consists of students receiving traditional instruction.
[b] Major groupings of d/E values in responses to scale question.
[c] Number of responses
[d] Percentage of all students in d/E group whose response to phase question was in *Correct* category
[e] Percentage of all students in d/E group whose response to phase question was in *Shadow* category
[f] Percentage of all students in d/E group whose response to phase question was in *Blocking* category
[g] Percentage of all students in d/E group whose response to phase question was in *All Other* category

Table 29: Category Breakdown According to d/E Group for Group C [a]

	Group C- First Survey (*N*=64)					Group C- Second Survey (*N*=66)				
d/E [b]	*N* [c]	% [d] Correct	% [e] Shadow	% [f] Blocking	% [g] All Other	*N* [c]	% [d] Correct	% [e] Shadow	% [f] Blocking	% [g] All Othe
0<d/E<3	57	11	16	25	49	26	19	27	12	42
3► d/E<10	6	33	17	33	17	24	13	33	8	46
d/E ► 10	1	100	-	-	-	16	31	31	6	31

[a] Group C consists of students receiving special instruction.
[b] Major groupings of d/E values in responses to scale question.
[c] Number of responses
[d] Percentage of all students in d/E group whose response to phase question was in *Correct* category
[e] Percentage of all students in d/E group whose response to phase question was in *Shadow* category
[f] Percentage of all students in d/E group whose response to phase question was in *Blocking* category
[g] Percentage of all students in d/E group whose response to phase question was in *All Other* category

were asked about the shadows on the Moon from the Earth. The students at the time said there were no shadows and seemed to understand the cause of the lunar phases slightly better. When it came time to do answer the surveys, these students showed an increase in the *Shadow* category. This was definitely unintentional and will need to be remedied for future instruction. Also, instruction may not have been intensive enough. Maybe more instruction or more activities would have helped students. The only way to know for sure is to get surveys from more students.

This research did show that instruction of any type will increase what students' believe is the Earth-Moon distance and that instruction can help move students from incorrect explanations of the lunar phases to explanations that contain fragments of the correct explanation.

5.4 Future Work and Ideas

Future work for this research can be broken into four main areas. First, more students are needed to take the surveys to get more data. Perhaps with a larger, more varied sample a connection between the explanations of the lunar phases and the scale of the Earth-Moon system could be found. Also, more data show different connections then what was originally looked for in this research sample. Secondly, the survey needs to be redesigned to get better student responses. The second question, the scale question, will be broken into two parts to clarify student conceptions. The first question, on the causes of the lunar phases, will still need to be open-ended, but a second part that lets students actually choose responses may be needed to help get a clearer understanding of student conceptions. Third, instruction on scale models and lunar phases needs to be redesigned to be more effective. Activities, worksheets or ideas for instructors need to be developed to help explain this topic to students. The phases of Venus could be used as an example. Better instruction may help students overcome their misconceptions. Whatever the new instructional method is, it needs to be easy for teachers to implement and inexpensive. Finally, the research needs to look at a possible connection between the causes of the lunar phases and some other conception.

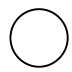
What do students who think the lunar phases are caused by shadows think causes eclipses? Is there a connection there?

More research in this area in general is needed. Researchers need to find out what students think and where they get their ideas from on lunar phases and the size of the Earth-Moon system. There has to be some connection between a student's scale model of the Earth-Moon system and her conception of the causes of the Moon phases; it is just not clear what that connection is at this time.

APPENDIX A. FIRST SURVEY

This in-class activity will be used to develop better methods of teaching Astro 120. Please answer to the best of your ability. This will in no way affect your grade in this class. Try to write clearly and legibly.

1. Explain, as clearly as you can, why it is that the Moon sometimes appears as a full bright circle like this,



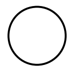
and sometimes the Moon can appear as a crescent like this,

2. On the back of this page, draw the Earth-Moon System as a scale model. (This means draw the Earth and the Moon the correct sizes relative to each other. Also, make sure to show the Earth and Moon the correct relative distance apart from each other.) Don't worry about being too accurate. Please explain why you drew the Earth-Moon System the way you did.

APPENDIX B. SECOND SURVEY

This in-class activity will be used to develop better methods of teaching Astro 120. Please answer to the best of your ability. This will in no way affect your grade in this class. Try to write clearly and legibly.

1. Explain, as clearly as you can, why it is that the Moon sometimes appears as a full bright circle like this,



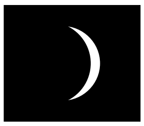
and sometimes the Moon can appear as a crescent like this,

2. On the back of this page, draw the Earth-Moon System as a scale model. (This means draw the Earth and the Moon the correct sizes relative to each other. Also, make sure to show the Earth and Moon the correct relative distance apart from each other.) Don't worry about being too accurate. Please explain why you drew the Earth-Moon System the way you did. Additionally, please label all items in your drawing.

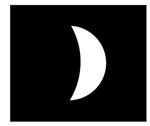
APPENDIX C. QUESTIONS FROM RESEARCH

Questions from Sadler (1992)
Correct answers are underlined.

2. One night you looked at the Moon and saw this:



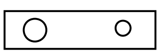
A few days later you looked again and saw this:

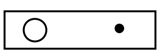


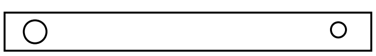
Why did the Moon change shape?

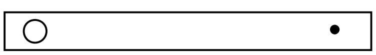
A. Something passed in front of it.
B. It moved out of the Earth's shadow.
C. It moved out of the Sun's shadow.
D. Its far side is always dark.
E. None of the Above

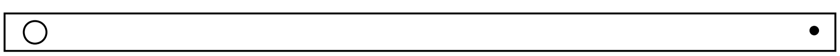
11. Which is the most accurate model of the Earth and Moon in relative size and distance from the Earth?

A. 

B. 

C. 

D. 

E. 

The larger object in each model is the Earth.

15. Choose the best estimates of the distance to the Moon from the Earth.

A. 1,000 miles
B. 10,000 miles
C. 100,000 miles
D. 1,000,000 miles
E. 10,000,000 miles

Bisard et al. (1994)

6. The different shapes of the Moon (or phases) are caused by:
   A. clouds on Earth.
   B. the Earth's shadow.
   C. viewing reflected sunlight off the Moon during the month.
   D. The varying angle of the sunlight off the Earth.

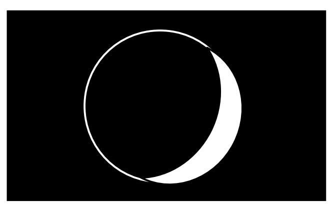
Zeilik et al. (1995)

4. The Moon has an angular diameter of about 1/2 degree in the sky. For an object that spans 1 degree, its distance-to-diameter ratio is roughly 50. Imagine that a tennis ball (6 centimeters in diameter) represented the actual diameter of the Moon. If you are making a scale model of the Earth-Moon system, you would then place the Moon at a distance of ___________ from the Earth.

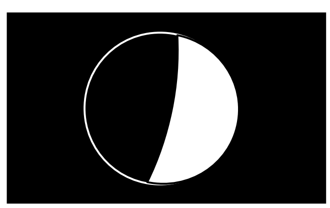
   A. 6 centimeters
   B. 60 centimeters
   C. 600 centimeters
   D. 6000 centimeters

15. The diagrams here show how the Moon appeared one night, and then how it appeared a few nights LATER. What do you think best describes the reason for the change in the Moon's appearance?

One night



Few nights later



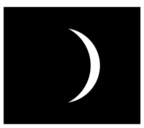
   A. The Moon moves into the Earth's shadow.
   B. The Moon moves into the Sun's shadow.
   C. The Moon is black on one side, white on the other, and rotates
   D. The Moon moves around the Earth.

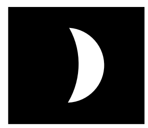
Targan (1993)

2. Draw a diagram and explain in your own words what causes the sequence of phases that you described above. In your diagram, please refer to the phases you shaded above by number (1, 2, 3, 4, 5, 6, 7, 8), explaining how <u>each</u> of those phases were caused. Use arrows to show the direction(s) of motion for any celestial bodies that move.

Trumper (2000)

2. The diagrams below show how the Moon appeared one night, and then how it appeared a few nights later. What do you think best describes the reason for the change in the Moon's appearance?





A. The Moon moves into the Earth's shadow.
B. The Moon moves into the Sun's shadow.
C. The Moon is black on one side, white on the other, and rotates.
D. The Moon moves around the Earth.

APPENDIX D. DIAGRAMS FROM TEXTBOOKS

Figure D1. Illustration of the lunar phases from *Journey to the Cosmic Frontier, 2nd edition updated.* pg. 24 Fix, J.D. McGraw-Hill 2001.

Figure D2. Illustration of the lunar phases from *Introductory Astronomy and Astrophysics, 3rd edition.* pg 55. Zeilik, Gregory, Smith, Saunders 1992.

Figure D3 and D4. The top figure shows a scale drawing of the Earth-Moon system. The second figure illustrates the lunar phases. Both are taken from *Voyages to the Planets, 2nd edition,* D3 from pg. 7 and D4 from pg. 69. Fraknoi, Morrison, Wolff, Saunders 2000.

Figure D5. Illustration of the lunar phases from *Astronomy Today, 2nd edition.* pg 16. Chaisson / McMillan, Prentice Hall 1996.

APPENDIX E. ADDITIONAL TABLES

Tables are given in percentage of students and are for Group A, all students.

Table E1. Other Category, First Survey, Student Responses for Earth/Moon and Distance/Earth (*N*=74)

	0<d/E<1	1▶ d/E<3	3 ▶ d/E<10	10▶ d/E <20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1		9	3	1			14
1▶ E/M<3	12	16	1			1	36
3▶ E/M<5	16	12					28
5▶ E/M<10	12	4					16
E/M▶ 10	4	1					5
Total	45	49	4	1		1	74

Note: 4 students had no ratios in this category.

Table E2. Other Category, Second Survey, Earth/Moon Radius compared to Distance/Earth Radii, Student Responses (*N* =65)

	0<d/E<1	1▶ d/E<3	3 ▶ d/E<10	10▶ d/E <20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1			3	2		2	6
1▶ E/M<3	5	17	9		2	2	34
3▶ E/M<5	5	6	14	3	5		32
5▶ E/M<10	6	6	8				20
E/M▶ 10		3	2	3			8
Total	15	32	35	8	6	4	65

Note: 4 students did not have ratios in this category.

Table E3. Rotation of Moon and Reflection of sunlight, First Survey, Student responses for Earth/Moon and Distance/Earth (*N* =13)

	0<d/E<1	1▶ d/E<3	3▶ d/E <10	10▶ d/E <20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1			8				8
1▶ E/M<3	8			8			15
3▶ E/M<5	31	15		8			54
5▶ E/M<10	15	8					23
E/M▶ 10							
Total	54	23	8	15			13

Note: Two students did not have ratios in this category.

Table E4. Rotation of Moon and Reflection of sunlight, Second Survey, Student responses for Earth/Moon and Distance/Earth (*N* =25)

	0<d/E<1	1▶ d/E<3	3▶ d/E <10	10▶ d/E <20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1		4					4
1▶ E/M<3	4	8	16	8			36
3▶ E/M<5		8	12	4	4	4	32
5▶ E/M<10		4	4	8			16
E/M▶ 10		8	4				12
Total	4	32	36	20	4	4	25

Table E5. Rotation of Moon, First Survey, Student responses for Earth/Moon and Distance/Earth (*N* =15)

	0<d/E<1	1▶ d/E<3	3▶ d/E <10	10▶ d/E <20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1	7						7
1▶ E/M<3	27	7					33
3▶ E/M<5	7	7	7				20
5▶ E/M<10	20	13					33
E/M▶ 10		7					7
Total	60	33	7				15

Table E6. Rotation of Moon, Second Survey, Student responses for Earth/Moon and Distance/Earth (*N* =15)

	0<d/E<1	1▶ d/E<3	3▶ d/E <10	10▶ d/E <20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1							
1▶ E/M<3	20	20			13		23
3▶ E/M<5	7		13	7			27
5▶ E/M<10				13			13
E/M▶ 10	7						7
Total	33	20	13	20	13		15

Note: Two students did not have ratios in this category

Table E7. Position of Moon, First Survey, Student responses for Earth/Moon and Distance/Earth (*N* =5)

	0<d/E<1	1▶ d/E<3	3▶ d/E <10	10▶ d/E<20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1							
1▶ E/M<3							
3▶ E/M<5	20	20			20		60
5▶ E/M<10	20	20					40
E/M▶ 10							
Total	40	40			20		5

Table E8. Position of Moon, Second Survey, Student responses for Earth/Moon and Distance/Earth (*N* =30)

	0<d/E<1	1▶ d/E<3	3▶ d/E<1(	10▶ d/E<2(	20▶ d/E<4(	d/E▶ 4(	Total
0<E/M<1							
1▶ E/M<3		10	17	7			33
3▶ E/M<5	7	17	13		3		40
5▶ E/M<1(	3	10	3	3			20
E/M▶ 10	3	3					7
Total	13	40	33	10	3		30

Note: Two students did not give a ratio in this category.

Table E9. Combination, First Survey, Student responses for Earth/Moon and Distance/Earth (*N* =18)

	0<d/E<1	1▶ d/E<3	3▶ d/E<1(	10▶ d/E<2(	20▶ d/E<4(	d/E▶ 4(	Total
0<E/M<1		6	6				11
1▶ E/M<3	17	11					28
3▶ E/M<5	17	6					22
5▶ E/M<1(	22	11					33
E/M▶ 10	6						6
Total	61	33	6				18

Note: Three students did not give a ratio in this category.

Table E10. Combination, Second Survey, Student responses for Earth/Moon and Distance/Earth (*N* =5)

	0<d/E<1	1▶ d/E<3	3▶ d/E <1(	10▶ d/E <2(	20▶ d/E<4(	d/E▶ 4(	Total
0<E/M<1							
1▶ E/M<3		20	20				40
3▶ E/M<5	20	20					40
5▶ E/M<1(	20						20
E/M▶ 10							
Total	40	40	20				5

Table E11. Reflection of sunlight, First Survey, Student responses for Earth/Moon and Distance/Earth (*N* =28)

	0<d/E<1	1▶ d/E<3	3▶ d/E <10	10▶ d/E <20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1		4	4				7
1▶ E/M<3	4	18					21
3▶ E/M<5	7	18	4				29
5▶ E/M<10	21	7	4				32
E/M▶ 10	7	4					11
Total	39	50	11				28

Note: Eight students did not give a ratio in this category.

Table E12. Reflection of sunlight, Second Survey, Student responses for Earth/Moon and Distance/Earth (*N* =28)

	0<d/E<1	1▶ d/E<3	3▶ d/E<10	10▶ d/E <20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1		4	4				7
1▶ E/M<3		4	11		7	4	25
3▶ E/M<5	11	11	11	4			36
5▶ E/M<10		4	11	11	4		29
E/M▶ 10			4				4
Total	11	21	39	14	11	4	28

Note: Two students did not give a ratio in this category.

Table E13. Correct, First Survey, Student responses for Earth/Moon and Distance/Earth (*N* =41)

	0<d/E<1	1▶ d/E<3	3▶ d/E<10	10▶ d/E<20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1		2					2
1▶ E/M<3	5	7	5		2		20
3▶ E/M<5	24	15	5	2	2		49
5▶ E/M<10	17	5	2	2			27
E/M▶ 10	2						2
Total	49	29	12	5	5		41

Note: One student did not give a ratio in this category.

Table E14. Correct, Second Survey, Student responses for Earth/Moon and Distance/Earth (*N* =34)

	0<d/E<1	1▶ d/E<3	3▶ d/E<10	10▶ d/E<20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1							
1▶ E/M<3	6	6	9	6	6		32
3▶ E/M<5	3	6	12	15	15	3	53
5▶ E/M<10	6			3			9
E/M▶ 10		3	3				6
Total	15	15	24	24	21	3	34

Note: One student did not give a ratio in this category.

Table E15. Blocking, First Survey, Student responses for Earth/Moon and Distance/Earth (*N* = 82)

	0<d/E<1	1▶ d/E<3	3▶ d/E <10	10▶ d/E<20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1		1	2				4
1▶ E/M<3	16	16	2				34
3▶ E/M<5	7	13	4	1			26
5▶ E/M<10	16	7	1				24
E/M▶ 10	7	4	1				12
Total	46	41	11	1			82

Note: Eleven students did not give a ratio in this category.

Table E16. Blocking, Second Survey, Student responses for Earth/Moon and Distance/Earth (*N* = 44)

	0<d/E<1	1▶ d/E<3	3▶ d/E <10	10▶ d/E<20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1		2	2			2	7
1▶ E/M<3	11	18	5		7		41
3▶ E/M<5	7	11	2	5		2	27
5▶ E/M<10	2	9	2	5			18
E/M▶ 10	2	2		2			7
Total	23	43	11	11	7	5	44

Table E17. Shadow, First Survey, Student responses for Earth/Moon and Distance/Earth (*N* = 79)

	0<d/E<1	1▶ d/E<3	3▶ d/E <10	10▶ d/E<20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1		1					1
1▶ E/M<3	10	6	4	1			22
3▶ E/M<5	16	11	3	1		1	33
5▶ E/M<10	20	5	5				30
E/M▶ 10	9	4	1				14
Total	56	28	13	3		1	79

Note: Five students did not give a ratio for this category.

Table E18. Shadow, Second Survey, Student responses for Earth/Moon and Distance/Earth (*N* =74)

	0<d/E<1	1▶ d/E<3	3▶ d/E<10	10▶ d/E<20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1	1		1		1		4
1▶ E/M<3	3	12	11	3	5	1	35
3▶ E/M<5	5	9	11	5	3		34
5▶ E/M<10	3	8	4	3	3		20
E/M▶ 10	3	3	1				7
Total	15	32	28	11	12	1	74

Note: One student did not give a ratio for this category.

Table E19. Rotation of Earth, First Survey, Student responses for Earth/Moon and Distance/Earth (*N* =21)

	0<d/E<1	1▶ d/E<3	3▶ d/E<10	10▶ d/E<20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1			19				19
1▶ E/M<3	14	14					29
3▶ E/M<5	14	19	5				38
5▶ E/M<10	5	10					14
E/M▶ 10							
Total	33	43	24				21

Note: Three students did not give a ratio for this category.

Table E20. Rotation of Earth, Second Survey, Student responses for Earth/Moon and Distance/Earth (*N* =5)

	0<d/E<1	1▶ d/E<3	3▶ d/E<10	10▶ d/E<20	20▶ d/E<40	d/E▶ 40	Total
0<E/M<1							
1▶ E/M<3	20	20	40				80
3▶ E/M<5	20						20
5▶ E/M<10							
E/M▶ 10							
Total	40	20	40				5

APPENDIX F. INTERVIEW TRANSCRIPTS

The following are partial transcripts of interviews that took place in Spring 2000 at Iowa State Univeristy. The questions are given in bold text; student responses in plain text. If a student used models or drew pictures, this is noted in italics. Four interviews were unable to be transcribed because of audio problems. Table F1 gives the diameter of each ball used in the interviews.

Table F1: Diameter (in inches) of Balls.

Ball	D (in)
basketball	12
blue ball	8
green ball	6
styrofoam ball	2.75
tennis ball	2.6
defuzzed tennis ball	2.4
large Superball	2.4
Ping-Pong ball	1.4
small Superball	1
green Superball	1.7
ball bearing	1.5

004-001

Why do you see these different pictures each night?

uhm because of the rotation of the Moon and the way it moves around we see different sides of the Moon, we don't see different sides of the Moon, we see different views in the way Sun reflects off the Moon.

If this was my Earth (blue ball) and this were my Moon (Styrofoam ball) what's going on?

The Moon is still here but the Sun is reflecting off it differently which is making us see it differently. *(Circles hand around Moon like an orbit*).

004-002

So you have drawn all these different Moon pictures what, why does the Moon look different night after night?

Why does the Moon look different?
(Student gets basketball and defuzzed tennis ball)
ok so what the Moon does is it rotates with the Earth.. and I guess it depends on, rotates with the Earth and the Sun is like over here and then when they rotate *(student gets large superball and puts it to the left of the basketball)* and it depends on where the sunlight is and where it hits on the Moon. so like when it rotates. (*student has Sun and Moon rotating around Earth)* That demonstration in recitation with the little balls, light and tennis ball, yea and it just depends on when the Moon and the Earth rotates in a synchronous fashion so when the Sun rotates sometimes it hits the Moon just on its side and other times it hits right in the middle and makes one side dark and one side light and sometimes it is all covered with light and sometimes none of it is showing

004-005

Why does the Moon look different night after night?

Because it's going around the Earth.

Moon's going around the Earth? And what does that have to do with it?

It means it varies how much you can see of it.

What does? The Moon makes the ..

Where you are at on the Earth. When it is over here you can't see as much of it because of what the Sun's reflecting back.

So where you are on Earth determines how much of the Moon you see?

Well, depending. As it goes around you don't see as much of it each night.

Why do you think that?

Because it is going around the Earth. It just depends on how much you can see as it goes around.

004-007

Why does the Moon look different night after night?

Because the Earth is in a different area around the Sun. And you only see parts of the Moon that the light's reflected off of.

Ok, so what does that have to do with the Earth?

Well you're seeing it from different points of view.

Seeing what?

The Moon.

004-008

So why does the Moon look different night after night?

Cause of the Sun. Because the Moon goes around the Earth and then the Sun shining on the Moon then the light shining on the Moon is what we see. And so we block part of the Moon.

Who blocks part of the Moon?

The Earth does.

The Earth does? Ok. You are saying that the Sun's here, the Earth's here and the Moon's over there..

No it doesn’t do that then. I can't remember what it was. There's the Earth *(draws Earth)*, there's the Sun *(draws Sun)*. It's just how the Sun hits the Moon. Like if the Sun's here, we aren't going to see the Moon cause its hitting..

Where's the Moon at? You don't have the Moon.

It's right here *(draws Moon in between Earth and Sun)* It's just where the Moon is and how much sunlight hits it.

How much sunlight hits the Moon?

See back here we'll see a full Moon. *(draws Moon behind Earth)* cause its all hitting. And here we'll only see half it probably but I don’t know *(draws Moon to the side of Earth)*

What about over here? *(points to the side of the Earth where no Moon is drawn)*

See half of it again.

Would it be a different half or the same half?

Other half. (*mumbles)* Then quarter, 3/4, 3/4 quarter. *(points to positions on picture)*

How did you come up with this?

My head. Just logic.

0400-012

Why does the Moon look different night after night?

Cause the Sun, Earth and the Moon are at a different angle, so the Sun reflects off it differently.

Off of what differently?

The Sun hits the Moon at a different angle, so it bounces back from the Earth at a different angle that we see.

How is the Earth involved?

The Earth, it's the Moon, (*decides to draw, draws Earth, Moon and Sun*.) We have the Earth and the Sun, so if the Moon was here (*positioned on top of Earth*) and the Sun was hitting it, we would see this part of the Moon, so we'd see this part would be dark over here and this part would be light over her. Here (*full Moon position*) we would see that a lot more of it would be light.

0400-013

Why does the Moon look different night after night?

Because it's *(draws Earth, Moon, Sun with Moon in between Earth and Sun*) That would be a lunar phase.

Lunar phases, what do you mean by that?

Well, a lunar eclipse. The Moon moves positions so it is not aligned with the Sun and that's why they have lunar eclipses. When the Moon is, …it moves, as the Moon moves out, it moves out of the shadow, talking about the wrong thing…(*moves to balls)* I know that there is no way the new Moon and the full Moon can be in the same area. Same time, … *(goes back to drawing, starts drawing graph (sky map))*

Why are you drawing this again?

Cause this is the path across the sky, of the Earth, this the path of the Sun. Then the Moon is, is a little bit off from the Sun. So when you have, the new Moon goes with the Sun, as the full Moon is opposite the Sun, because ..

What do you mean by goes with? What are you thinking?

I am trying to remember what I mean when I say goes with.

I just want to know why there are Moon phases, that's it, that's all.

It's like, the Sun *(long pause)*

Why do we see different phases of the Moon?

Cause the Moon moves across the sky of the Earth.

004-014

Why does the Moon look different night after night?

Because of the fact the Earth is revolving and the Moon is revolving. The different, we will see different parts, well the shadows. The light reflected from the Sun it going to make shadows on the Moon and when they get into a perfect line we wouldn't see any of it because it would be an eclipse.

004-015

Why does the Moon look different night after night?

Because of the , it has something to do with the Earth's rotation and how cause… (*gets balls out*) The Earth's rotation and the Sun reflecting on the Moon.

How does the Earth fit in?

(draws Earth and Moon) So the Earth, (*draws Sun*) The Moon revolves around the Earth and the Earth revolves around the Sun. so as the Moon revolves around the Earth we only see one side of it.

Why do we see Moon phases again?

Because of the way the Earth progresses along its revolution of the Sun and how it revolves…

0400-016

Why does the Moon look different night after night? Why does it go through these little drawings?

sunlight reflected off the Earth. It depends on where the Earth is for how much. The Earth will go around the Sun and the Moon will go around the Earth and depending where the Earth is there is going to be different sunlight.

So it depends on where the Earth is?

Yes. When it is between the Moon and Sun it is new Moon and when it is on the other side you have a full Moon. I know it is reflected sunlight from the Earth to the Moon.

So the light hits the Earth and then the Moon. And you said the new Moon is back here?

Yes. You can't see it because no light that's getting back to it.

And why is the light not getting back to it?

Because all the light's over here, there is nothing for it to reflect back to it.

0400-017

Why does the Moon look different night after night?

Position relative to the Earth and Sun. The Earth casts a shadow on, or else, the position of the Earth. *(gets out a Sun, Earth and Moon ball)* The Earth is here and the Moon goes around like this (*orbits Moon around Earth)*. Starts here in the shadow of the Sun, the light from the Sun on the Moon is the same except the Moon moves around and we see different parts of it.

And you were saying something about shadows? How do the shadows come in?

Oh that's an eclipse.

So you've changed your mind about the shadows?

Yea.

0400-018

Why does the Moon look different night after night?

Because its catching up and it rotates faster than the Sun or something. This is like the Sun and its like going this way *(moves blue ball*), The Moon is like behind it but going faster (*ping pong ball*). When its over here, the Sun stays in the same place, and the Moon is over here (*right of Sun) (gets Earth, aligns balls Moon, Earth, Sun*) If the Sun's there and this is the Earth and the Moons over there and they are right in a line then this would be a new Moon.. If it's going this way, only a little bit of sunlight it would be hitting the Moon, only this side of the ball would would get lit. Then when it got over here then only this half would be lit (quarter position) when it right of front of it it is an eclipse or something and/ or full Moon or something. (*Earth,* *Moon, Sun*) Then it comes over here and only half of it gets it. *(quarter Moon*) Then it goes back to here. *(Moon, Earth, Sun)*

You said that when the Moon is right here we have a lunar eclipse (Moon between Earth and Sun). We don't have a lunar eclipse every month, though.

That's true. It is always a full Moon when it is over here *(between Earth and Sun*). It must have something to do with the tilt or something.

0400-019

Why does the Moon look different night after night?

Cause these are changing (*points to Moon drawings*)

Why are these changing?

Cause the Moon is in a different position in the sky with the planet and the Sun so the light from the Sun reflects differently amounts of light depending on where the Sun and the Moon are. *(draws pictures to explain*)

0400-021 (Audio problems)

Why does the Moon look different night after night?

It's going around. *(starts drawing Earth, Moon, Sun)*. It's different because the sunlight shines on it and we're in the same spot. So we see more and more and then less and less.

If I were to take out the Earth, would the Moon phases change?

They would stay the same.

004-023

So why do we have Moon phases?

Because of the shadow, the Earth's shadow.

Can you draw a picture explaining it to me?

Sure. *Draws picture.* Audio gets really really bad. Says something about light being blocked out.

What phase is the Moon in up here?

Half.

And here?

Then we'd see well, we wouldn't see anything. (*says something else can't make out.)*

But you said that over here we wouldn't see anything.

Well we'd still see a little.

0400-024

Why does the Moon look different night after night? Why do we have Moon phases?

Cause of the rotation of the Earth.

And how does that effect it?

It depends on the side we are seeing, the angle of the shadow like the Earth is *(moves hands to rotate symbolize Earth rotation) (draws Earth Moon and Sun)* As we are rotating or whatever, the shadow that we see if we are looking at it causes us to see only part of it.

Where does the shadow come from?

The shadows coming from the Earth, in front of it.

What does the Earth rotate around.

The orbit of the Earth

Does the Moon go around the Earth

I cant remember, I think it does, the Moon goes around, not the Earth.

Ok so you think that either the Moon goes around the Earth or the Earth goes around the Moon?

The Earth goes around the Moon.

Why do you think that way?

It just makes sense.

0400-025 (bad static)

Why does the Moon look different night after night?

It has to do with the place, or how the Earth is, the shadow.

Could you explain that?

It has to do with the way the Sun, sometimes the Moon is between the Sun and the Earth, just the reflection, the shadow it casts.

What shadow?

The shadow that the Earth casts.

What you are saying is that you have the Sun, the Moon and the Earth, and the Earth is casting a shadow,

No. The Moon, no *(draws Earth and Moon, Sun)* The way the Sun reflects this way, sometimes you can see different parts. Like we will always see the same side of the Moon but this is, there is a shadow, I can't remember which one is in the way.

How do you get a crescent Moon?

Because of how much, it must be the Earth in the way of the Sun. The Earth is in the way of the Sun.

0400-027

Why do we see Moon phases?

Cause the Moon travels around the Earth that's what we see lighted up.

0400-028 (hard to make out)

Why does the Moon look different night after night?

Depends on the part with the shadows

Shadows from what?

From planets and the Sun.

004-030

Why do we have Moon phases?

The way Sun reflects onto the Moon and the Earth's shadow on the Moon. That's how we see it.

So you have the Sun, the Earth and the Moon. The Sun reflects light onto the Moon and the Earth shadow..

The Earth blocks some of it so you can only see…

How does that work?

Uses balls. As the Earth and the Moon go around, we wouldn't be able to see cause there is no sunlight getting to it. (*Moon, Earth, Sun alignment)*. But if it is over here, we would be able to see some of it because the Earth is still blocking some of it. (*quarter Moon position)* Like over here (*crescent)* block out the Sun at the right angle, but it has to be at the right distance and angle. That would be a solar eclipse.

So this blocks out the Sun?

(solar eclipse alignment). This blocks the Sun from our view.

What happens if it is not at the right angle?

Then we just see part of the Moon and part of the Sun..

So is that the phase that would be full Moon?

No. *(puts balls into correct full Moon alignment)*

But earlier you said that was new Moon.

I am really confused now. I am not sure anymore. I know we have phases cause the Moon goes around the Earth and the Earth goes around the Sun but I can't remember anymore where the phases are.

But how do the shadows work in?

How do the shadows work in? Now I don't know. I kinda thought the Earth had part of a shadow on the Moon and that's why we couldn't see it because part of it was out.

But now you are finding that it is not working? Why do you think it is not working?

I am just really good at second guessing myself. I am just going to go with that the Earth has some sort of shadow on the Moon so then you can't see part of it.

004-031

Why does the Moon have phases?

Because it is in different positions around the Earth according to where the Sun is.

So what does that mean?

That it's not the Earth's shadow. It's just where we, I'll draw it out.
Proceeds to draw textbook picture.
Here we see all of it, here we see some of it and here none of it.

0400-032

Why do we have Moon phases?

(gets Moon, Earth and Sun ball) When they are all in a line, you can't see the Moon at all cause there is no sunlight on the Moon. *(Moon, Earth, Sun order*). As the Sun goes around then you can see little by little. It's the sunlight.

Does the Moon go around the Earth, or does the Earth go around the Moon?

The Moon goes around the Earth.
So what happens when your Moon is right here? *(points to spot between Earth and Sun)*
(long pause) This must be full Moon.

And that's because there is no Earth shadow on the Moon?

Right

What about here? (*quarter Moon spot*)

You can see like 3/4 of it

0400-033

Why do we have Moon phases?

The Sun and the Earth *(has balls for them*) The Earth is tilted 23.5 degrees.

And this causes the Moon phases?

No The tilt doesn't change but the rotation. I think it's the rotation of the Earth and it is also moving around.

Where's the Moon in all this?

The Moon is out here (*around Earth*)

What if I take the Sun out and you get and Earth and Moon, show me how the Moon phases happen. *(assume Sun is really far away)*

(long pause)

If the Sun is over here (points to wall) where would the Moon be for a full Moon?

(*places Moon between Sun and Earth*)

And why would it be right here?

Because it is in full view of the Sun.

So we on Earth would see a full Moon?

Yes

What would happen if my Moon was back here (behind Earth)?

It would be a new Moon.

And why is that?

Cause there is no light coming, it hits the Earth before it hits the Moon.

And what would happen if I put my Moon here? (puts Moon in front of Earth)

We would have a solar eclipse.

Do we have a solar eclipse every month?

No

But we have Moon phases every month

I know we have Moon phases every month, I just.. I wouldn’t think so that we would have a solar eclipse every month. Because the Earth, man I don’t know, I want to say we do, maybe it is a different kind of eclipse

0400-034

Why does the Moon look different night after night?

Cause, uhm, it's blocking the Sun, so that you only see a sliver of it because the Sun is

Where is the Sun.

(draws Sun) Cause the Moon blocks the Sun so its like *(draws Moon really close to Sun)*

Where is the Earth in all this?

(draws Earth underneath Sun)

Ok so the reason we see Moon phases is because the Moon is blocked, is in front of the Sun?

(looks at me funny)

Ok so why do you have the Moon up here?

Up there?

Why do you have the Moon in front of the Sun?

that's where it goes.

What would happen if I were to put your Moon back there (points to underneath Earth)?

Oh, then we wouldn't see the Sun, OH, then we wouldn’t see the Moon because no sunlight could hit it.

So we wouldn’t see the Moon when it is back here, but as long as its in front we see it, but what if it is on the side?

I wouldn't see it.

So we only see it when it is directly..

Yes

How did you figure that out, where did you learn that?

I guess it is just from my parents I guess, the Sun is light so something has got to be behind light to see it.

0400-035

Why do we have Moon phases?

Well the Moon going around the Earth. and then… (*gets basketball for Sun, green ball for Earth and defuzzed tennis ball for Moon*. The Moon goes around the Earth and the Earth goes around the Sun. And it is just how the Sun reflects onto the Moon and that is how much we see throughout the month.

So, you said something about the Earth rotating around the Sun, would it matter if I were to say put the Sun over there, would it change the Moon phases *(points to wall*)

No, uhm, see I in class, he shows it in a circle and then on that diagram when it follows the ecliptic or whatever. There is like the first quarter, third quarter and full Moon. Yea, so I would say it would change if the Sun is on the other side. The first and third quarter they would change. like one side would be dark if it is first quarter and then when you go to the other side the other side would be dark and it would be like third quarter.

0400-036

So why does the Moon look different night after night?

Oh cause of where it's positioned in relation to the Earth whether it is off to the side or directly behind the Earth. When it is directly behind the Earth it is a full Moon more or less. Not directly behind but enough so that the all the Sun is reflected off the planet Earth.

0400-037

Why does the Moon look different night after night?

Cause the reflection of the Sun. like the Earth rotates and so that there is a Moon on one side like it hits the Earth in different spots, hits the Moon. (*she mumbled*)

Ok so what we have is the Sun and you are saying it shines light on the Earth and because we rotate the light that hits the Earth hits it in different places and then bounces and hits the Moon? Is that what you are trying to tell me?

I guess but that doesn't sound right. *(draws Sun, Earth and draws Moon above Earth)* and then I think the Sun the rays actually hit the Moon and then it reflects.

So why do we see different phases?

because it hits the Moon in different spots.

So the Moon is always here *(above Earth*)?

No.

What happens when the Moon is say, right here? (*behind Earth*)

That's why we see different, cause if it is back there light doesn't get to the Moon.

Light doesn't get to the Moon?

Or it does but like, if we are over here, but that doesn't make sense either.

Ok so back here, there is no Moon is that what you are saying?

Well if you are over here. (*points to side of Earth facing opposite Moon)*

But what if you are over here? (*side of Earth facing Moon*) What would you see?

I don't know.

What would happen if the Moon is over here? *(underneath Earth*)?

then you would just see like this part of the Moon.

What would happen if I were to put the Moon here? *(between Earth and Sun*)

then you don't see it. So here you see the full Moon (*points to Moon behind the Earth).*

004-038

Why do we have Moon phases?

Because the Earth is blocking the Sun or it is not blocking the Sun.

It is or it isn't?

At different, depends on the phase. (*Draws Sun, Earth, Moon)*

So how come we have Moon phases?

Because the Moon is in different positions. Like when it is right here (*quarter Moon position)* And where right here (*facing the Moon from Earth)* We only see half of it because the Sun is shining on that half. And when it is right here *(new Moon position*) we can't see it because the Sun is shining on the other side so we only see the dark side. And when it is back here *(full Moon position*) we can see it all or it could be an eclipse.

When we first started this question before I had you draw it, you were saying that the Earth blocks it. What did you mean?

I meant it could block it as an eclipse.

0400-041

Why does the Moon look different night after night?

You mean like the shape?

Yes, why do we have Moon phases?

the revolution uhm the rotation of the Earth. not the Sun er not the Moon cause we always see te same side of the Moon.

How does the rotation of the Earth give us Moon phases?

I know the Earth and the Moon both revolve at the same speed, that is why we always see

So they both rotate at the same speed……

yea but this one goes around the Earth. maybe they don't go at the same speed but they go at the same time so we always see the same side. As far as the Moon phases the Sun comes into that. And that has to do with our revolution.

So if this is the Sun *(takes green ball*) what is going on?

(*she moves balls around to simulate the orbits.)* Do you get it?

Ok if we are here (*places Earth in middle of table*) where would the Moon be for full Moon?

I don't even know.

What happens if I were to put the Moon here? *(between Earth and Sun*)

not an equinox, an eclipse.

So we have an eclipse here (*between Earth and Sun)* what happens if I put the Moon here? *(underneath Earth*)

You can see the whole thing?

You can see the whole thing?

Well the half that we can see.

So we would see the entire half that we could normally see?

Yes

What happens if I put the Moon here *(behind Earth*)?

We can't see it. New Moon

Why is it a new Moon back here?

Because the Earth blocks the Sun's light.

Ok so what happens if I put it over here? *(above Earth*)

Then it is the same as down here. (*points to under Earth)*

0400-042

Why does the Moon look different night after night?

Cause of the axis that we are spinning*. (takes 2 balls and moves them around each other. switches which is the Earth and which is the Moon. Blue ball Moon and green ball Earth)*

We see Moon phases because the Earth is going around the Moon?

Yea.

So we are spinning and we are going around the Moon and that is why we see Moon phases?

Sure.

Are you sure?

I guess.

Could you show me where a full Moon would be?

Like here, we would see the full side of it. (*has Earth by me and Moon by wall)*

Where is the Sun in this?

I know there is sometime where you can only always only see half of the Moon. Cause you can only see half. Let's see the Sun. I don't know.

Ok, let's say the Sun is where I am. Can you show me where a full Moon would be?

Like there. (*Sun-Earth-Moon*)

And this is the Earth (green ball) and that's the Moon (blue ball)?

Yes.

Where would a crescent Moon be?

(moves Earth to about 5 on a watch face)

Where would new Moon be?

(*Earth-Moon- Sun*)

0400-043

Why does the Moon look different night after night?

Because what you see is the reflection of the Sun. As the Sun hits the Moon on different sides we see less and less of the reflected part from the Earth. *(draws textbook picture and explains)*

0400-046

Why do we have Moon phases?

Because the Earth rotates and the Moon also rotates. well the Moon always has the one face facing us.

So how does it work with the Moon and Earth rotating?

How does it work?

Here is the Moon (gray ball) and here is the Earth (blue ball) and the Sun is the basketball over there. Can you show me a full Moon?

The full Moon would be, the light region is completely facing the Earth.

How does that work with the rotation then?

the rotation?

Right, you said that the Moon phases were caused by the rotation of the Earth and the Moon?

Isn't it because the tidal forces are pulling on it that it keeps the one face. I don't know why. I just know that it causes the seasons er phases of the Moon.

Can you show me where a new Moon would be?

I have no idea.

***(I draw a crescent Moon on the gray ball*) Can you show me know?**

I remember. *(I draw a person on the blue ball)* As you go around…

What Moon phase would you see if the Moon was back here? (*Sun Earth Moon)*

new Moon

And why is that?

I have no idea.

You remember what the new Moon phase is right? New Moon is when you can't see the Moon. So you are saying when the Moon is back here we don't see it?

Yes.

Why don't we see it?

Because the Moon rotates around the Earth like we rotate around the Sun. So it's away from us.

Ok let's say is nighttime and we are facing the same direction as the Moon and over here it is new Moon phase, at night we wouldn't be able to see it. Why wouldn't we be able to see it?

I don't know how to describe this.

Ok so there is the light from the Sun. So we have a new Moon phase that means we can't see the Moon.

Correct.

So what does that tell you about the light from the Sun.

It's not reflecting off the Moon.

So if you are back here, would you be able to have light reflecting off the Moon.

No.

And why not?

Because the Earth is blocking the sunlight.

What phase is it over here? (*between Earth and Sun*)

Full Moon.

0500-01

Why do we have Moon phases?

Because of the reflection off the Sun and the Earth. It is in the way. Ok, here is the Sun (*styrofoam ball*) the Earth, *(big superball*) and the Moon (*black ball*). There is going to be a 5 degree difference. and as it goes around there is just a shadow that is cast from the Sun off the Earth and onto the Moon.

The Sun casts a shadow?

No actually the Earth is casting the shadow.

And the shadow causes the Moon phases?

Yes.

Ok so what Moon do I get here? *(Sun, Earth, Moon)*

Well that is completely blocking it so you would see new.

What Moon do I get here? *(Sun, Moon, Earth*)

Full.

And then here? (*Moon under Earth*)

3^{rd}

And then here? (*Moon above Earth*)

First.

005-002

Why do we have Moon phases?

Because of the Moon rotates around the Sun and it's elliptical, it's like Earth's it rotates on a slant. *(uses balls)*

The Moon is always going like this (*rotates the Moon around Earth*) the same side is always facing us. (*at first student has Moon going around Sun, when questioned she decided she needed an Earth, she then rotates Earth around the Sun with the Moon rotating around the Earth.)*

And that's why we have Moon phases.

Can you show me where full Moon would be?

Full Moon would be (*long pauses, first makes it Sun, Moon, Earth)* No, I don't think it would be illuminated at all. (*puts Moon back between Sun and Earth)* The new Moon would be here (*Sun, Earth, Moon)*

Why would the new Moon be back here?

Because the Sun is, er the Earth is blocking the Sun from the Moon. So it's completely hidden.

So where would full Moon be?

My guess is to say right here (*Sun, Moon, Earth)* but I am not sure.

005-003

Why do we have Moon phases?

Due to the way the Sun hits the Moon.

What about the Earth? Does it have anything to do with it?

No.

005-004

Why does the Moon look different night after night?

Because of the tilt.

Tilt of what?

The Moon, ah, (pause) cause we see the same side of the Moon every day and night so it would be the tilt. Tilt **of** the Earth on the Moon, because of the tidal forces.

We have Moon phases because the Earth is tilted and we have tidal forces.

And that's why we see the same side of the Moon every night.

But how does that explain how it's phases are different. How one night we have a Moon that's all light up and one night we have a Moon that's banana shaped?

Because when the Earth turns you cant see what's like hidden.

Ok so the Moon's hidden and that's why we can't see, that's why we see like banana shaped and stuff.

Yes

Is there anyway you could use the balls or draw it.

(uses ping pong ball for Moon and Styrofoam ball for Earth, Sun is way off to side, long pause, rotates Moon around Earth)

If I asked you to show me how you would get a new Moon, could you show me?

(pause) There's a shadow, that's why there were different shadows cast. (*Student brings up demonstration done in recitation and tries to apply it here, she is questioned about what the demonstration was about)* I was behind the Sun when I saw a new Moon. (*Moon, Sun, Earth)* Well maybe it is in-between..

When did you see a full Moon?

Oh that would have been a full Moon, behind the Sun because of the lamp, which, so I would have been behind the Moon

So how would I get the Earth, Moon and Sun to line up so that I would get a new Moon?

(Student is confused and I draw a Sun and Earth and Moon)

What would happen if I put the Moon here. (Moon Earth Sun)

It's dark it's the … here probably be the full Moon cause the Sun is shining on it. (*points to space between Earth and Sun)* no, yea (*gets ping pong ball out and moves it around the drawn Earth and Sun)* Here would be new Moon. *(Correctly identifies new Moon phase)* And here would be the full Moon I think. *(correctly identifies full Moon phase)*

Ok so why is full Moon over there and new Moon over here?

I can't get to it.

Ok what's a full Moon?

All light up.

So here you are telling me this is a full Moon but you just told me it was all dark and you just said a full Moon is all light up.

Well, Here would be a new Moon because no sunlight can get to this (*has Moon in correct spot, points to side facing Earth)* But here the full Moon, the sunlight can get to it so it would be all light up.(*moves Moon to correct position)*

005-005

Why does the Moon look different night after night?

Because of its positioning with respect to the Sun. The Sun reflects , er the Moon reflects the sunlight in different ways.

And how does the Earth factor into it?

Well, like, kind of depending on where you are on the Earth do you see the Moon differently.

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