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The Lunar Phases Project: A Mental Model-Based Observational Project for Undergraduate Nonscience Majors

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Abstract

We present our Lunar Phases Project, an ongoing effort utilizing students' actual observations within a mental model building framework to improve student understanding of the causes and process of the lunar phases. We implement this project with a sample of undergraduate, nonscience major students enrolled in a midsized public university located in the southeast part of the United States. To quantitatively assess our activity, we use the Lunar Phases Concept Inventory, a research-validated assessment instrument. We observe significant gains in student understanding of the lunar phases for students who complete the Lunar Phases Project.

1. INTRODUCTION AND MOTIVATION

The lunar phases are not a new concept for undergraduate students of any major. The National Science Education Standards presented by the National Research Council (1996) state that students graduating the 8th grade should understand the causes of the lunar phases. However, misconceptions and misunderstandings of the lunar phases persist throughout high school and college education (Schneps 1989; Bailey and Slater 2003 and references therein). The growing field of research into astronomy education provides an excellent opportunity to improve upon the teaching of the lunar phases.

Recent results reveal a clear need for a more hands-on, constructivist approach to the teaching of lunar phases (Kavanagh, Agan, and Sneider 2005). Traditional classroom instruction is not sufficient for students to be able to construct a correct mental model of the lunar phases (Kavanagh, Agan, and Sneider 2005). In-class instruction augmented with a 3D instead of a 2D visual model has been implemented for lunar phases' instruction, but again with no significant effect on student learning (Cid and Lopez 2010). The importance of mental model building (MMB) in astronomy education is becoming clear for students of all ages. In the MMB methodology, students must incorporate spatial visualization and spatial orientation in their understanding of a concept (e.g., Padalkar and Ramadas 2007 and references therein).

As described by Schmidt and Stepans (2011), MMB is an instructional method designed to help students visualize the content they are studying. It is particularly useful for understanding abstract concepts such as processes and phenomena not easily seen. This methodology allows the students to create models in the form of drawings, diagrams, or physical models to represent the content being studied. MMB leads the students through five phases in which they: (a) create a visual or concrete model that represents their preconceptions, (b) study information about the topic, (c) revise their models to demonstrate their new understanding, (d) present and justify their models, and (e) test the strength of their models and refine their thinking. The students then discuss and compare their own mental models with those of other classmates and assess how well their models explain the phenomena represented.

Taylor *et al*. (2003) report success with the mental model building approach to teaching the lunar phases with middle school-aged students. Curricula using the constructivist approach coupled with actual lunar observations have been created for middle school-aged students (e.g., Sneider 1986, 1998, Harvard-Smithsonian Center for Astrophysics 2000). More recently, both real and simulated observations of the Moon have been used to promote preservice teacher understanding of the lunar phases through conceptual change (Trundle and Bell 2010). However, the method of combining mental model building with real observations of lunar phases and a research-validated, widely used assessment tool is not well established in nonscience major undergraduate astronomy education.

In this project, the investigators work with a sample of undergraduate, nonscience major students from a midsized master's degree granting university located in the southeast part of the United States. Over half of the students attending the university come from the five-county area near the university and represent a diverse population in gender and ethnicity. Since 2000 the student population was over 55% female, as high as 65% in 2001. As of Fall 2010, just under 15% of the student population is Hispanic. African Americans are the fastest growing racial/ethnic group on campus, growing from 568 students in Fall 2009 to 719 in Fall 2010 in a total student population of about 12 000. Demographic statistics were used from the University's official documentation found in a December 2010 report.

2. IMPLEMENTING THE LUNAR PHASES PROJECT

The Lunar Phases Project was implemented in undergraduate introductory astronomy (AST2004) and physical science (ISC1002) courses almost every semester since Spring of 2009. Focusing the project efforts in undergraduate astronomy courses allows the investigators to reach the broadest cross-section of students. From the results of Rudolph *et al*. (2010): Introductory astronomy courses affect "… the scientific literacy of all types of college students: men and women, native and non-native English speakers, all ethnicities, all majors, and students of all academic abilities. For many of these students, this is the last science course they will ever take." The physical science course attracts a similar demographic of students interested in a variety of sciences including astronomy. In addition, the physical science course allows the project results to be generalized not just to astronomy students, but to all nonscience major undergraduate students taking introductory science classes. This project focuses on an astronomical topic, but the observational methodology and incorporation of the scientific method can support instruction in a variety of sciences.

Study participants were comprised of 45% females and 50% males, with 5% of participants not answering the question regarding gender. The vast majority of participants were 20 years old or younger with 78%; 10% were 21–23 years of age; and 3% were 24–30 and 31 or older, respectively. Four percent of participants did not provide an age range. In regard to ethic background, 72% of participants were White/non-Hispanic, and 10% were Hispanic-American. Three percent of participants indicated they were multicultural; 2% of participants were African American and Asian-American, respectively; and 1% were Native American and African (not American), respectively. Five percent of participants declined to answer.

Participants in the study included students from a variety of academic majors. Students were prompted to indicate their current area of interest if their current major was undecided. Twenty-six percent of participants indicated Humanities, Social Science, or the Arts as their major; 24% were Business, 11% Education; and 12% selected Science, Engineering, Agriculture, or Architecture. Twenty-four percent of participants selected "Other" indicating their major was not one of the responses available.

The MMB methodology provided the conceptual framework for the Lunar Phases Project. As applied to the lunar phases, the MMB methodology is used to elucidate students' original models of the causes of the lunar phases. The Lunar Phases Project then provides a framework from which students create models that describe the correct spatial orientation of the Sun–Earth–Moon system in various phases. This approach helps students to develop and hone their spatial visualization skills by applying them to actual observations of the Moon (Mon and Meyer 2010, Urquhart, Mon, and Meyer 2011). Here, the Lunar Phases Project will be summarized using the MMB framework, followed by a detailed description of the project. Before beginning the project, students create a model representing what they believe causes the phases of the Moon, thus fulfilling the first step of MMB.

Students are strongly encouraged to use diagrams in their model (and most students do so), but students may also express their preconceptions in writing. During the project, students follow the second step of MMB by collecting information about the lunar phases by directly observing them. Throughout the project, students are given opportunities to revisit their models by learning to associate the Moon's appearance and location in the sky at various times with the corresponding location in the Moon's orbit. Near the end of the Lunar Phases Project, students must express their new model of the lunar phases by creating a visual model representing the Sun-Earth-Moon orientations responsible for the lunar phases they observed. The students also justify their models by providing a postproject explanation for the lunar phases. Although the models are created individually, students discuss their models with each other. Finally, the MMB process is completed with students testing the strength of their models by making predictions about both the lunar phase and the corresponding location of the Moon in its orbit at selected future times. Students wrap up the project by completing a final pair of observations that allows them to test their predictions and refine their thinking.

At the beginning of the project, the students receive some basic information from the instructors: The Moon orbits the Earth, the Earth orbits the Sun, and it takes about 29.5 days for the Moon to complete one cycle of phases. The Earth–Sun and Earth–Moon distances are also provided. The instructors also provide students with a table of moonrise and moonset times as published online by the U.S. Naval Observatory (http://www.usno.navy.mil/USNO/). Next, students are shown a diagram of the Sun, Earth, and Moon as they would appear from far above Earth's North Pole so that the instructor can describe the counterclockwise direction of the orbits of the Earth and Moon, and the counterclockwise rotation of the Earth. Finally, the instructor demonstrates how to tell time at various locations on Earth's surface by combining the direction to the Sun with Earth's counterclockwise rotation.

During the Lunar Phases Project, the students gather observational data through about one and a quarter lunar phase cycles using sextants built in class. The instructors choose project dates that begin when the Moon is near the first quarter phase since the Moon will be easily observable throughout the evening for the students' first observations. Students complete observations on their own time. Students are asked to complete at least two observations per week at times compatible both with their schedules and the Moon's rise and set times. Once a week they confirm and share their observations in small groups from which they progressively draw the Moon's appearance and the corresponding position in its orbit. In order to draw the Moon at the appropriate location in its orbit, students must incorporate their observations of the Moon's altitude and location in the sky (either in the eastern or western part of the sky), and the time the observation was made. During the early weeks of the project, the instructor assists the class in this process by using sample observations drawn from the class to demonstrate how to place the Moon in its orbit. After the observations have been completed, a prediction and a last follow-up observation are made to confirm the students' understanding and provide for further corrections if needed. At the end of the Lunar Phases Project, each student hands in a "portfolio" consisting of their weekly observations and plots, their final predictions and observations, and a final model of the lunar phases summarized in one drawing along with a written explanation for the actual cause of the phases of the Moon. Figures 1–4 show samples of completed student work on the Lunar Phases Project.

As students complete the Lunar Phases Project, they are continuously gathering real observations, and each week they have time to interpret their observations and begin to build a model that either supports or contradicts their original hypotheses of the cause and process of the lunar phases. In order to qualitatively investigate students' comprehension, they are also asked to express in writing and/or diagrams their understanding of the cause of the Moon phases and the use of the scientific method. The project is bookended by opportunities for the students to first describe their initial conceptions of the lunar phases, and then at the end to state their new ideas and model (see Figures 5 and 6 for samples of student work). In this way, students completing the Lunar Phases Project also benefit from the conceptual change model (CCM) (Schmidt, Saigo, and Stepans 2006). In this instructional methodology, students must first recognize and confront any prior misconceptions before getting the opportunity to meaningfully change and improve their conceptual knowledge. This process results in significant improvements in student understanding of challenging scientific concepts.

3. ASSESSMENT OF STUDENT LEARNING

In contemporary pedagogical research in astronomy, there is a demand for meaningful assessment tools. Published results indicate that conceptual understanding can be elucidated from research-based, concept-specific tools such as multiple-choice concept inventories (e.g., Bailey and Slater 2003). One highly successful example of such tools is the Lunar Phases Concept Inventory (LPCI), consisting of 20 conceptual questions and nine

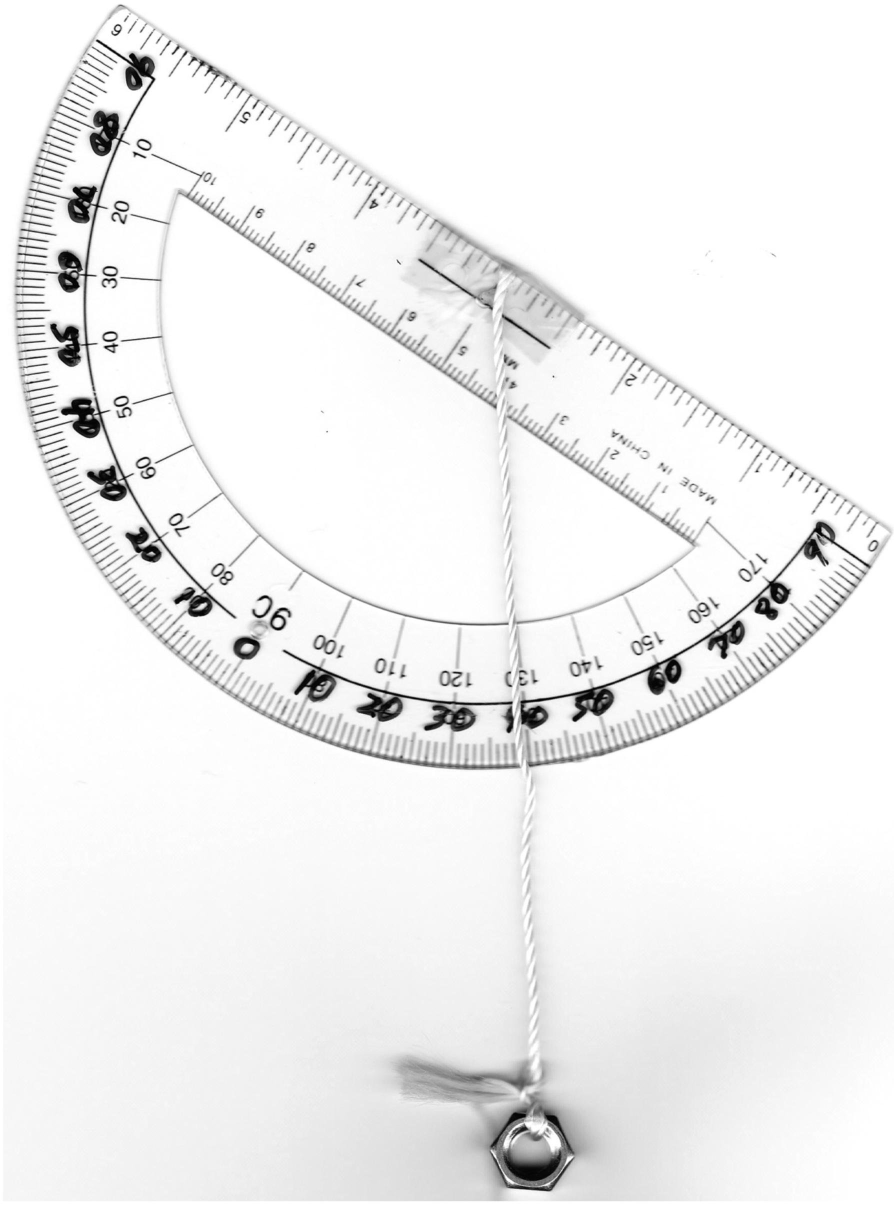
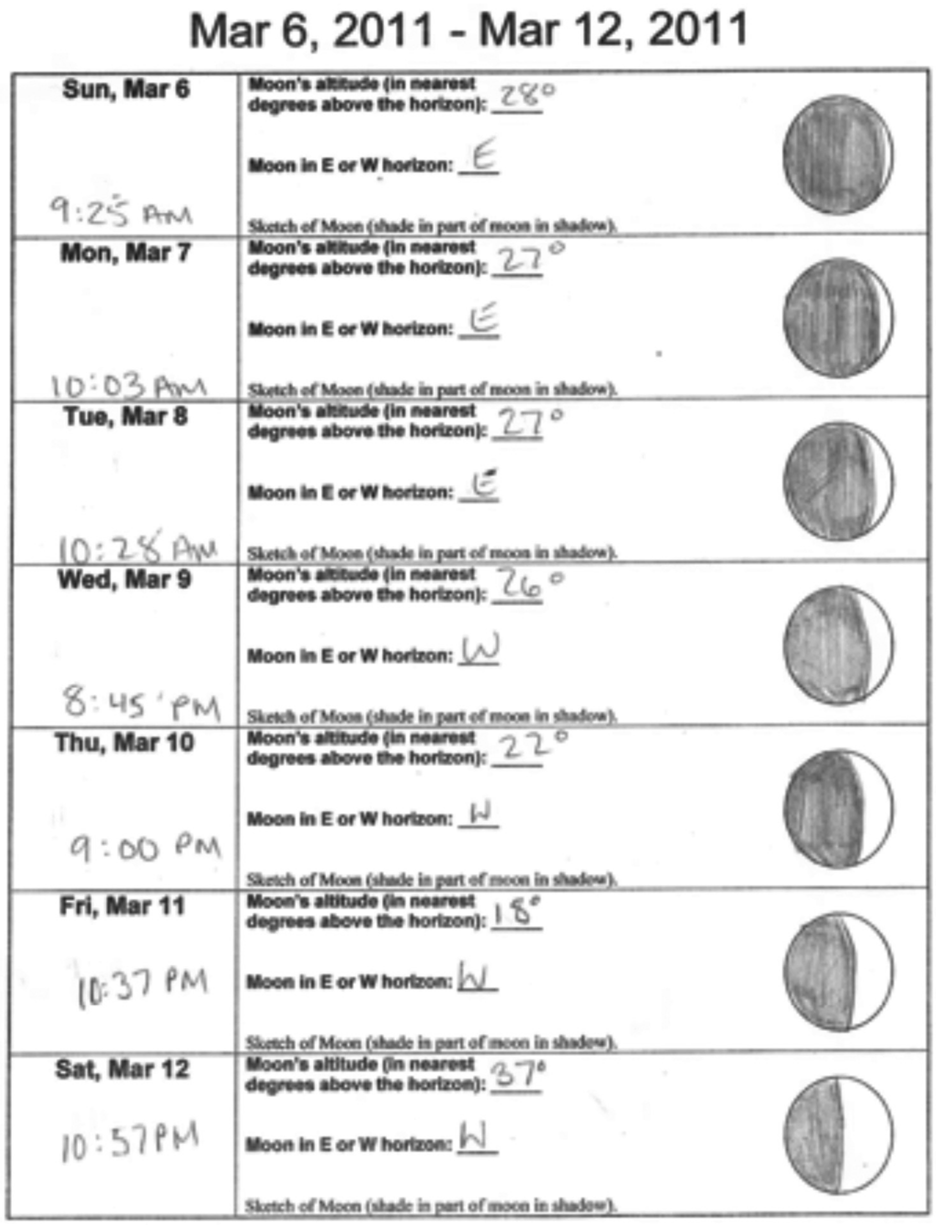


Figure 1. A student-made sextant

demographic questions (Lindell 2001; Lindell and Olsen 2002). The LPCI was created to be a reliable, research-based assessment tool that any astronomy instructor could use in an introductory-level course (Bardar *et al*. 2006 and references therein).

To assess the Lunar Phases Project, students are given the LPCI as a standard tool to gauge their preproject and postproject comprehension. As a preproject test, the LPCI is administered close to the project start time, within one week before beginning the project as the timing fits with other class activities. The students complete the preproject LPCI before receiving any in-class instruction on the lunar phases. The LPCI is administered as a post-project test the week after students complete their final models and in-class predictions. This timing was chosen to give students time to contemplate their new view of the lunar phases as they complete their final observations, and to ask any last questions they may have before demonstrating their understanding of the LPCI questions.

The Lunar Phases Project was implemented in a pilot study in 2009 and continued since then in introductory astronomy and physical science courses. To date, over 270 undergraduate students have completed the Lunar Phases Project and the LPCI administered both as a pretest and post-test to gauge the efficacy of the Lunar Phases Project. To preliminarily assess the students' improvement on the LPCI, the investigators chose to use the normalized gain "g" following Hake (1998):


Mar 6, 2011 - Mar 12, 2011

Sun, Mar 6 9:25 PM	Moon's altitude (in nearest degrees above the horizon): 28° Moon in E or W horizon: E Sketch of Moon (shade in part of moon in shadow).
Mon, Mar 7 10:03 PM	Moon's altitude (in nearest degrees above the horizon): 27° Moon in E or W horizon: E Sketch of Moon (shade in part of moon in shadow).
Tue, Mar 8 10:28 PM	Moon's altitude (in nearest degrees above the horizon): 27° Moon in E or W horizon: E Sketch of Moon (shade in part of moon in shadow).
Wed, Mar 9 8:45 PM	Moon's altitude (in nearest degrees above the horizon): 26° Moon in E or W horizon: W Sketch of Moon (shade in part of moon in shadow).
Thu, Mar 10 9:00 PM	Moon's altitude (in nearest degrees above the horizon): 22° Moon in E or W horizon: W Sketch of Moon (shade in part of moon in shadow).
Fri, Mar 11 10:37 PM	Moon's altitude (in nearest degrees above the horizon): 18° Moon in E or W horizon: W Sketch of Moon (shade in part of moon in shadow).
Sat, Mar 12 10:57 PM	Moon's altitude (in nearest degrees above the horizon): 37° Moon in E or W horizon: W Sketch of Moon (shade in part of moon in shadow).

Figure 2. A student's completed observation calendar

$$g = (\%\text{post-test} - \%\text{pretest})/(100 - \%\text{pretest}).$$

The LPCI average score went from about 41% to 56% across all students (these results are discussed in detail in Section 3.1). The average g varies greatly from class to class; the lowest was 0.06, the highest was 0.47, and the mean was 0.23. A g of at least 0.30 indicates that the project is effective at improving many students' performance on the chosen concept inventory (Hake 1998). The preproject and postproject scores on the LPCI combined with the preproject and postproject written explanations indicate significant improvement in students' understanding of the lunar phases concepts after completing the Lunar Phases Project.

3.1. Detailed Analysis of Results

A paired-samples t-test was conducted using SPSS (originally developed as the Statistical Package for the Social Sciences, now owned and developed by IBM) to determine whether the gains made from the preproject and post-project assessment were significant (Siegel 1991). Detailed statistical analysis was performed on the preproject and postproject LPCI scores using the method of t-tests for the entire sample. Individual t-tests were conducted

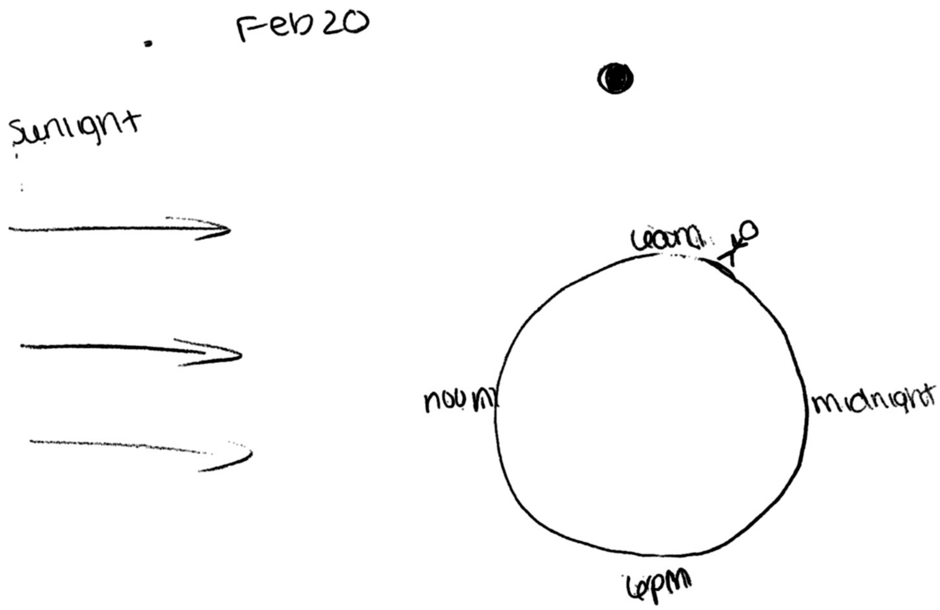


Figure 3. A student's completed weekly progress page

as a follow-up to further compare performance of students across courses and semesters (Siegel 1991). This section presents the subsequent results and analysis.

A paired-samples t-test was conducted for all of the students' scores from Spring 2009 to Spring 2011. Table 1 provides descriptive statistics for all scores. Results indicated that there was a significant difference in scores from the preproject (M = 8.26, SD = 2.90) and postproject (M = 11.13, SD = 3.66) scores; t (271) = 13.59, $p = 0.00$, $d = 0.88$ for all of the students in the study from 2009 to 2011 (see Table 2).

Preproject and postproject scores were compared by semester to take a closer look at the data using paired-samples t-tests. Table 3 provides descriptive statistics for scores by year and semester. Results indicated there

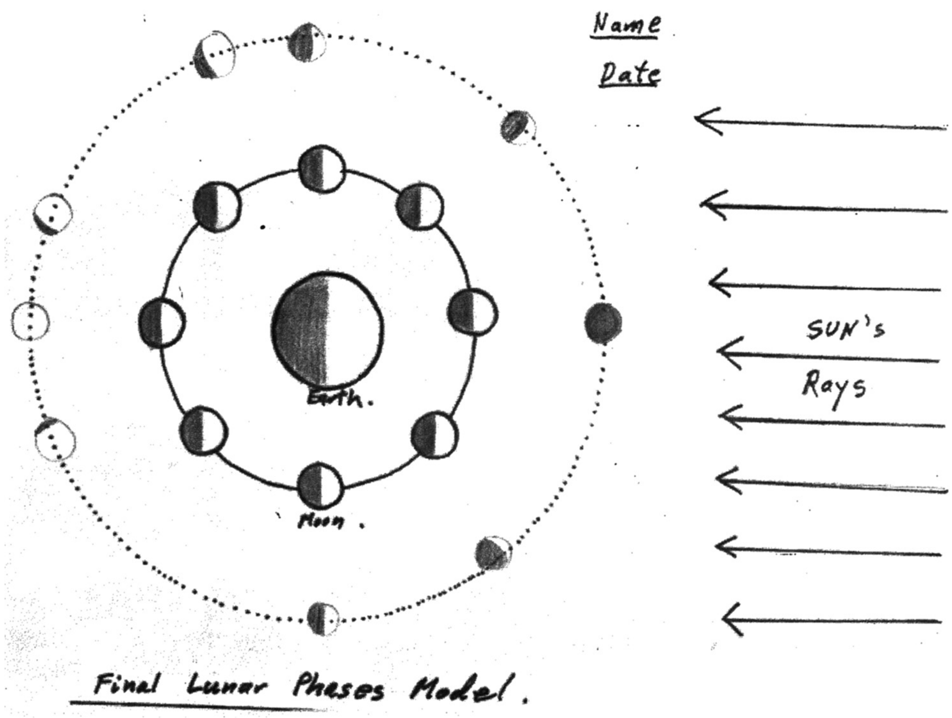


Figure 4. A student's completed final model. The inner circle represents the Moon's orbit around the Earth. The outer circle represents the Moon's appearance at various locations in its orbit as recorded in the students' own observations.

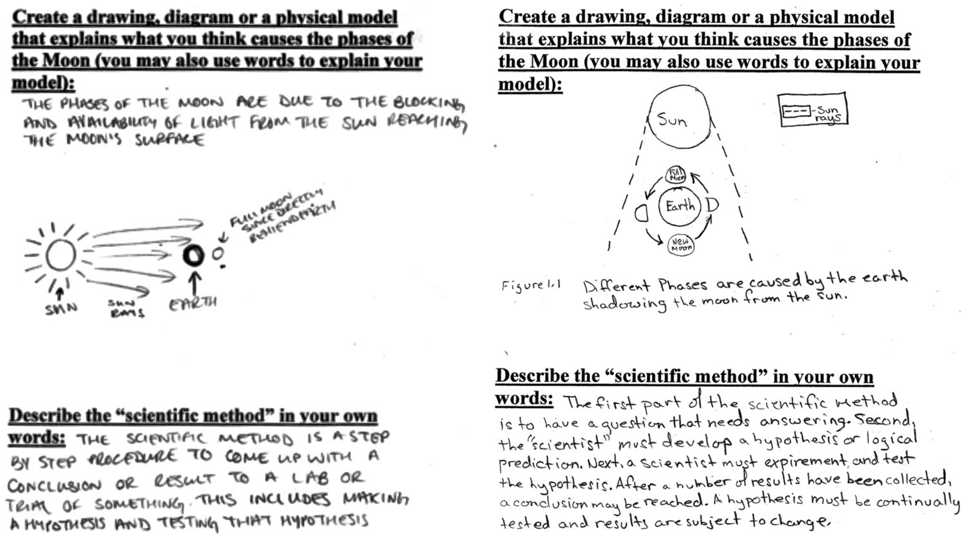


Figure 5. Samples of students' preproject description of the lunar phases and the scientific method

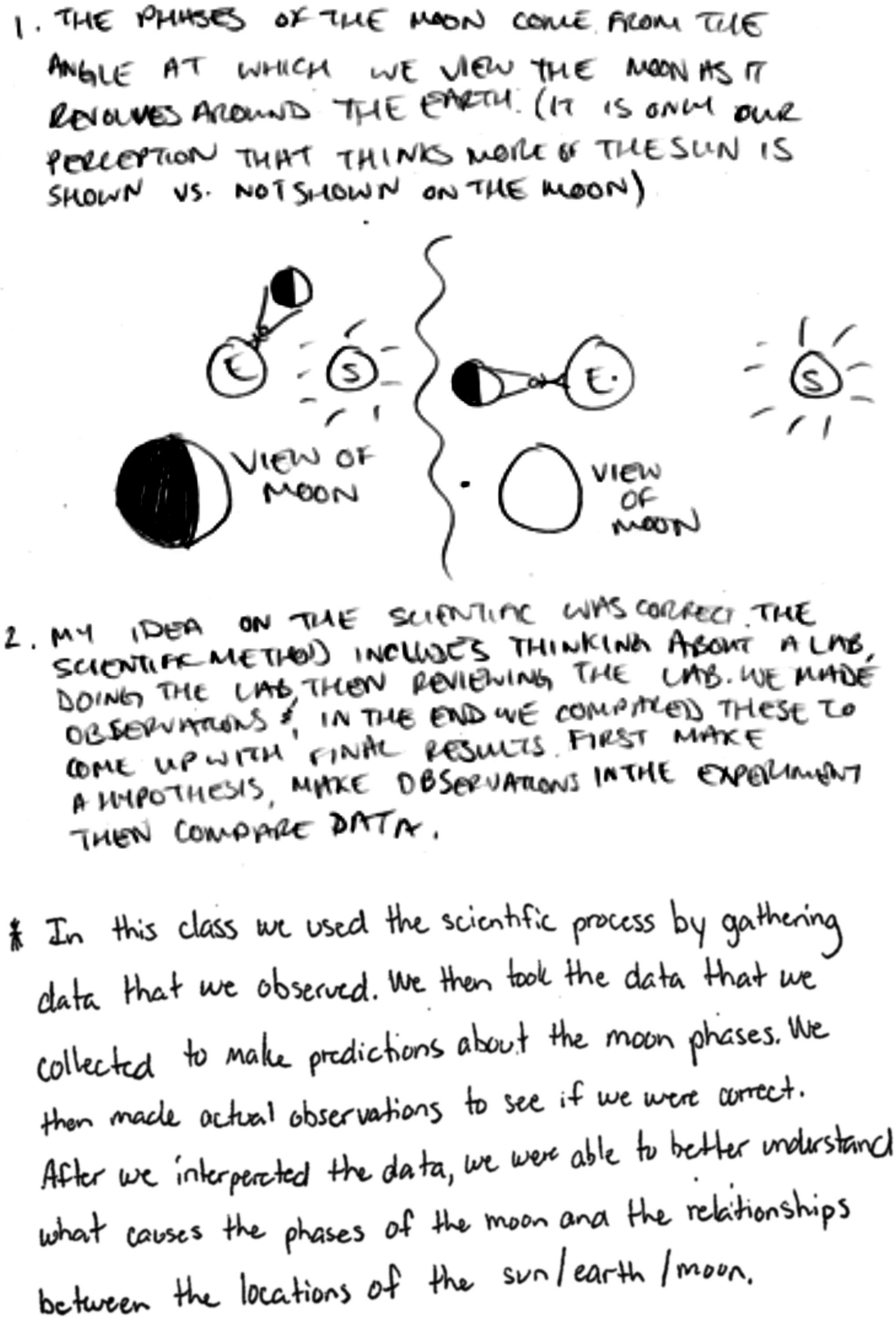
was a significant difference in the scores from the pre (M = 9.57, SD = 2.82) and post (M = 12.41, SD = 3.41); t (74) = 6.84, $p = 0.00$, $d = 0.90$ for the Fall 2009 semester. In addition, the spring semester for 2009, 2010, and 2011 each had significant gains with pre (M = 7.77, SD = 3.03) and post (M = 11.77, SD = 2.60); t (60) = 10.63, $p = 0.00$, $d = 1.43$ for Spring 2009, pre (M = 7.46, SD = 2.77), and post (M = 9.35, SD = 3.03); t (53) = 4.28, $p = 0.00$, d=0.65 for Spring 2010, and pre (M = 7.94, SD = 2.59) and post (M = 10.66, SD = 4.37); t (81) = 6.58, $p = 0.00$, $d = 0.78$ for Spring 2011 (Table 4).

Student gain scores were compared by course (AST2004 and ISC1002) to investigate any differences within the two courses. Table 5 provides descriptive statistics for scores by course. Results indicated there was a significant difference in the scores from the pre (M = 8.52, SD = 2.91) and post (M = 11.55, SD = 3.53); t (222) = 13.21, $p = 0.00$, $d = 0.94$ for the AST2004 course. In addition, there was a significant difference in the scores from the pre (M = 7.04, SD = 2.53) and post (M = 9.24, SD = 3.69); t (48) = 4.10, $p = 0.00$, $d = 0.71$ for the ISC1002 course. See Table 6 for full analysis details.

To determine the extent to which the gains were small or large in magnitude, the effect size was calculated using Cohen's d (Glass and Hopkins 1996). The gains for scores from all students in the study were large in magnitude based on the effect size ($d = 0.88$). Looking semester by semester, the Spring 2009 and Fall 2009 semesters can be described as having large gain scores, $d = 1.43$ and $d = 0.90$, respectively, and Spring 2010 and Spring 2011 semesters had medium or moderate gains in scores between preproject and postproject scores, $d = 0.65$ and $d = 0.78$, respectively. Comparing AST2004 and ISC1002 revealed a greater gain in scores for students enrolled in AST2004 ($d = 0.94$) than students enrolled in ISC1002 ($d = 0.71$).

4. DISCUSSION

The results from the preproject and postproject LPCI scores indicate that students who complete the Lunar Phases Project benefit from significant gains in understanding about the cause and process of the lunar phases. Differences in student performance stand out in two ways. Overall, students enrolled in AST2004 had larger gains than students enrolled in ISC1002. Although no definitive causes emerged based on the available data, there are possible reasons for this result. ISC1002 is a freshman-level course but AST2004 is a sophomore-level course. This may create a selection effect, with more advanced and engaged students more likely to be present in the AST2004 course. Also, while the AST2004 laboratory environment is not rigidly structured, it is a more structured environment than that of the ISC1002 course. In the AST2004 laboratories, students are asked during every session, regardless of topic, to complete work in groups, but that is not always the case for ISC1002, which features combined lecture/laboratory sessions. Students participating during Spring 2009, the first semester the Lunar Phases Project was implemented, showed significantly higher gains than students participating during other semesters. Students enrolled in both AST2004 and ISC1002 participated in the project during Spring 2009. There are no clear explanations for this result. The results of our analysis do not indicate that the observed


1. THE PHASES OF THE MOON COME FROM THE ANGLE AT WHICH WE VIEW THE MOON AS IT REVOLVES AROUND THE EARTH. (IT IS ONLY OUR PERCEPTION THAT THINKS MORE OF THE SUN IS SHOWN VS. NOT SHOWN ON THE MOON)

2. MY IDEA ON THE SCIENTIFIC WAS CORRECT. THE SCIENTIFIC METHOD INCLUDES THINKING ABOUT A LAB, DOING THE LAB, THEN REVIEWING THE LAB. WE MADE OBSERVATIONS *, IN THE END WE COMPARED THESE TO COME UP WITH FINAL RESULTS. FIRST MAKE A HYPOTHESIS, MAKE OBSERVATIONS IN THE EXPERIMENT THEN COMPARE DATA.

* In this class we used the scientific process by gathering data that we observed. We then took the data that we collected to make predictions about the moon phases. We then made actual observations to see if we were correct. After we interpercted the data, we were able to better understand what causes the phases of the moon and the relationships between the locations of the sun/earth/moon.

Figure 6. Samples of students' postproject descriptions of the lunar phases and the scientific method

differences in gains correlated with gender, ethnicity, major program of study, or any of the answers to the demographic questions on the LPCI.

The significant gains found from the preproject and postproject scores suggest a relationship between observed active class participation throughout the Lunar Phases Project and higher gain from pretest to post-test scores on

Table 1. Descriptive statistics for all students

	Mean	N	Std. deviation	Std. error mean
Pre	8.26	272	2.90	0.18
Post	11.13	272	3.66	0.22

Table 2. Comparisons between pretest and post-test for all students

	Mean	SD	SE mean	95% Confidence interval Lower	Upper	t	df	*p*
Pre–Post	2.88	3.49	0.21	3.29	2.46	13.59	271	0.00

the LPCI, but this is not something that the current data allows the investigators to quantify. However, future implementations of the Lunar Phases Project can incorporate quantifiable methods for gaining insight into student participation, as described in future work below.

4.1. Lessons Learned

Many "best practices" in implementing the Lunar Phases Project became apparent in the first iterations. The most significant of these practices are rooted in having the student complete the first observation during his or her evening laboratory session when possible, providing the incentive to continue beginning the Lunar Phases Project near the first quarter phase. The first observation is always the hardest for students since they are not quite sure what to expect, but in completing the first observation during laboratory, many questions can be answered quickly and subsequent observations are made much easier. After completing the first observation, students are familiar with correctly using their sextants to estimate the altitude of the Moon, how to determine whether the Moon is in the western or eastern sky from a familiar location, how to record their observation by shading in the part of the Moon in shadow, and how to correctly draw the Moon in a North-up, South-down orientation.

Another point of difficulty for students is their first weekly progress page, where they must begin translating their 3D observations into a 2D model. To complete this task, students must determine what location on Earth corresponds to their observation time based on a given Earth–Sun orientation, and how to determine the eastern and western horizon associated with that location. Two solutions have proved effective in assisting students here. The instructor may create a sample weekly progress model step-by-step using a real observation from the class. Also, students can be provided with an overlay sheet with an observer and their horizon already drawn. Students can place the observer at the appropriate location on Earth and instantly see where the horizon would be. This also assists students in plotting the Moon correctly based on the altitude recorded for their observation.

4.2. Future Work

The work done and the data and feedback collected thus far provide many goals for subsequent analysis and improvements for the Lunar Phases Project. The student experiences with the Lunar Phases Project can be further enriched in a few ways. After completing their final models (as in Figure 4), students can be given the opportunity to test their models in-class before taking the postproject LPCI. Students could be asked to make predictions about, for example, hypothetical Moon rise times at various phases using their own models. Students could then be given the opportunity to immediately test their predictions.

To help the students assess how well their models explain the phenomena of the Moon phases, they can compare their models derived through the MMB process with other established aids. They can use a Lunar Phases Planisphere (Shawl 2010) which uses a wheel in which the Moon revolves around the Earth while also showing

Table 3. Descriptive statistics for students by year and semester

Semester	Year	Time	N	Mean	SD	SE
Fall	2009	Pre	75	9.57	2.82	0.33
		Post	75	12.41	3.41	0.39
Spring	2009	Pre	61	7.77	3.03	0.39
		Post	61	11.77	2.60	0.33
	2010	Pre	54	7.46	2.77	0.38
		Post	54	9.35	3.03	0.41
	2011	Pre	82	7.94	2.59	0.29
		Post	82	10.66	4.37	0.48

Table 4. Comparisons in gains between pretest and post-test by year and semester

		Mean	Std. deviation	SE	95% Confidence interval Lower	Upper	t	df	*p*
Fall	2009	2.84	3.60	0.42	3.67	2.01	6.84	74	0.00
Spring	2009	4.00	2.94	0.38	4.75	3.25	10.63	60	0.00
	2010	1.89	3.24	0.44	2.77	1.00	4.28	53	0.00
	2011	2.72	3.74	0.41	3.54	1.90	6.58	81	0.00

how the Moon phase would appear at a given position in the Moon's orbit around the Earth. The planisphere can be used to verify their own 2D model as derived from their 3D observations. They can also verify their 3D outdoor observations by using balls and light projection to simulate the Sun-Earth-Moon positions. Students can observe the shadow created on a ball (Moon) as it goes around the student's head with the Sun simulated by a light source, thus portraying the Moon phases indoors in the classroom.

The students' preproject and postproject responses on the LPCI can be further analyzed incorporating methods of factor analysis and item response theory (IRT). Factor analysis can be used to investigate, for example, how questions on the LPCI might be grouped by topic. This provides a way to investigate what lunar phases concepts are best addressed by the Lunar Phases Project, as well as which concepts could be better integrated into the project. IRT provides an alternate, more rigorous method of analyzing student learning gains than normalized gains alone. This method has been used to evaluate concept inventories in other science fields but has only recently begun to be used in astronomy (Wallace and Bailey 2010). The assessment process itself could also be expanded to include a more reflective component. A validated self-assessment instrument such as the customizable student assessment of their learning gains (SALG) (Seymour *et al*. 2000) could be used to explore students' own assessment of their abilities and knowledge before and after completing the Lunar Phases Project.

Significant gains in student understanding have been reported by Bailey and Slater (2003) from the addition of in-class lunar phases exercises based on the constructivist approach to a traditional lecture (e.g., Prather *et al*. 2007). The Lunar Phases Project combined with an active learning in-class environment can integrate both in-class and out-of-class activities to achieve even higher gains in student understanding.

Finally, the Lunar Phases Project and the underlying methodologies can be used as a springboard for the development of future astronomy curriculum tools. Though real observations may not always be viable, virtual, or simulated observations can also be used effectively with college-level students (Trundle and Bell 2010). In order to develop meaningful curricular activities, instructors must be able to assess them properly. There are a growing number of research-validated concept inventories that instructors can use to assess gains in students' conceptual understanding. In astronomy, concept inventories also exist for, for example, properties of stars (Bailey 2008) and the nature of light and spectroscopy (Barder *et al*. 2007). Combining innovative, learning-centered activities with established concept inventories encourages the creation of innovative new curriculum tools that can be readily assessed with currently available instruments.

5. CONCLUSIONS

The initial results of the Lunar Phases Project are encouraging and, perhaps more importantly, have provided the creators of the project many constructive ways of improving the project. The addition of this observational

Table 5. Descriptive statistics for students by course

Course	Time	N	Mean	SD	SE
AST2004	Pre	223	8.52	2.91	0.20
	Post	223	11.55	3.53	0.24
ISC1002	Pre	49	7.04	2.53	0.36
	Post	49	9.24	3.69	0.53

Table 6. Comparisons in gains between pretest and post-test by course

Course		Mean	SD	SE	95% Confidence interval Lower	Upper	t	df	*p*
AST2004	Pre–Post	3.02	3.42	0.23	3.47	2.57	13.21	222	0.00
ISC1002	Pre–Post	2.20	3.76	0.54	3.29	1.12	4.10	48	0.00

project has given new depth to the introductory astronomy and physical science classes by encouraging significant application learning by the students, particularly the dimensions of skills (by performing observations) and critical thinking (by having students interpret their observations in order to create their own model, and to make predictions) (Fink 2003).

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