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The Impact of Stereo Display on Student Understanding of Phases of the Moon

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Abstract

Understanding lunar phases requires three-dimensional information about the relative positions of the Moon, Earth, and Sun, thus using a stereo display in instruction might improve student comprehension of lunar phases or other topics in basic astronomy. We conducted a laboratory (15 sections) on phases of the Moon as part of the introductory astronomy classes. Half of the laboratories were taught using stereo visualizations projected by a portable GeoWall system running the AstroWall software, while the other half of the laboratories were identical, but without stereo. We found that both sets of laboratories showed a statistically significant gain in student comprehension, but that there was no statistical difference between the stereo laboratories and the nonstereo laboratories. We conclude that there is no advantage to using a stereo display in teaching about lunar phases.

1. INTRODUCTION

Physics and astronomy have topics that are highly spatial in nature (i.e., electricity and magnetism, seasons, lunar phases, etc.). These topics are usually presented using two-dimensional (2D) representations, some of which might reinforce preconceived ideas or introduce new misconceptions about the three-dimensional (3D) system (e.g., Ambrose *et al.* 1999). A classic example of this problem is seasons, where textbook artists try to illustrate the path of the Earth around the Sun and often draw an elongated ellipse to present the Earth's elliptical orbit from a perspective view (see Figure 1). It is possible, then, that this 2D representation has now introduced a misconception that the Earth's orbit is an elongated ellipse when, in fact, it is almost circular (DeBuvitz 1990). In physics, there is evidence that the mental manipulation of 3D images plays a role in increasing cognitive load when dealing with magnetism and the relationship to currents (Lopez and Hamed 2004). Similarly, in astronomy, there are many topics in which 3D relationships are crucial to understanding the concept, thus we would expect that the manipulation of mental images would be an important source of cognitive load when trying to acquire a concept or accomplish a certain task that required the application of that astronomical content.

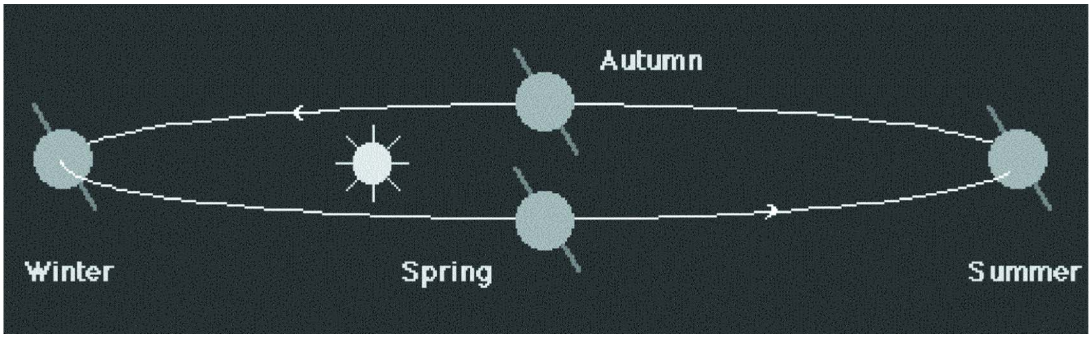

Figure 1. Example of a typical depiction of seasons trying to show how the Earth being closer to the sun does not cause summer; however, the dominant perceptual feature of the diagram is that the orbit of the Earth is an elongated ellipse

In this study, we examine student comprehension of the phases of the Moon, the impact of instruction in a single laboratory on that understanding, and the importance of an explicitly 3D representation of the topic. Misconceptions about phases of the Moon, by children and adults alike, have been a topic of study for some time (e.g., Schnepps and Sadler 1987; Trumper 2000; Trundle *et al.* 2002; Lindell and Olsen 2002; Bailey and Slater 2003). Given that the 3D spatial relationship between the Earth, Moon, and Sun is critical to understanding the phenomenon of phases, one might *a priori* consider that instruction which provides a 3D view of the system would hold an inherent advantage in instruction.

Pedagogy (e.g., McDermott and the Physics Education Group at the University of Washington 1996), based on active engagement techniques, has shown to improve student comprehension about phases of the Moon (McDermott *et al.* 2006; Trundle *et al.* 2002; Trundle *et al.* 2007), but it has been suggested that computer simulations can be more effective than some aspects of interactive experiences (e.g., Bell and Trundle 2008; Winn *et al.* 2006). More specifically, it has been suggested that 3D computer simulations can increase student comprehension of the phases of the Moon (Hansen *et al.* 2004; Küçüközer 2008; Küçüközer *et al.* 2009). One might expect such an outcome given that it is essential to understand the Sun-Earth-Moon system in 3D in order to fully understand lunar phases (and eclipses). There are studies indicating that a stereo display can be much more effective in communicating information for a particularly 3D intensive tasks (e.g., Ware and Franck 1996; Volbracht *et al.* 1997). There is also evidence that the effectiveness of a stereo display is task specific (Hubona *et al.* 1999), and that 2D perspective representations may, in certain circumstances, be just as effective as 3D representations (Cockburn and McKenzie 2002).

When considering whether or not to use a 3D display in instruction, there will be a trade-off between pedagogical effectiveness and cost and ease of use. A low-cost stereo projection system that has become popular in recent years is the Geowall system (www.geowall.org), which is comprised of two projectors stacked on top of each other fitted with polarized filters, one producing a 45° diagonal polarized image, while the other produces a diagonal polarized image perpendicular to the first image (see Figure 2). Two images of the same scene, but with a slight separation, are projected onto a special silver matted screen that allows for the light to retain its polarization when it is reflected. Viewers wear glasses with polarized filters (both eyes diagonally polarized to match the filters on the projectors) in order to get image separation and the stereo effect. This inexpensive stereo visualization system has been extensively used in undergraduate geoscience classrooms (Morin *et al.* 2003). Moreover, there is a freely available software package called AstroWall for viewing lunar phases and seasons (www.geowall.org/astrowall.html), and some evidence has been presented that use of the AstroWall had a positive effect for student comprehension on phases of the Moon (Turner *et al.* 2003). What is not known, however, is if the use of a stereo display in the context of teaching lunar phases provides a significant pedagogical advantage to make the use of a special projection system worth the time and effort.

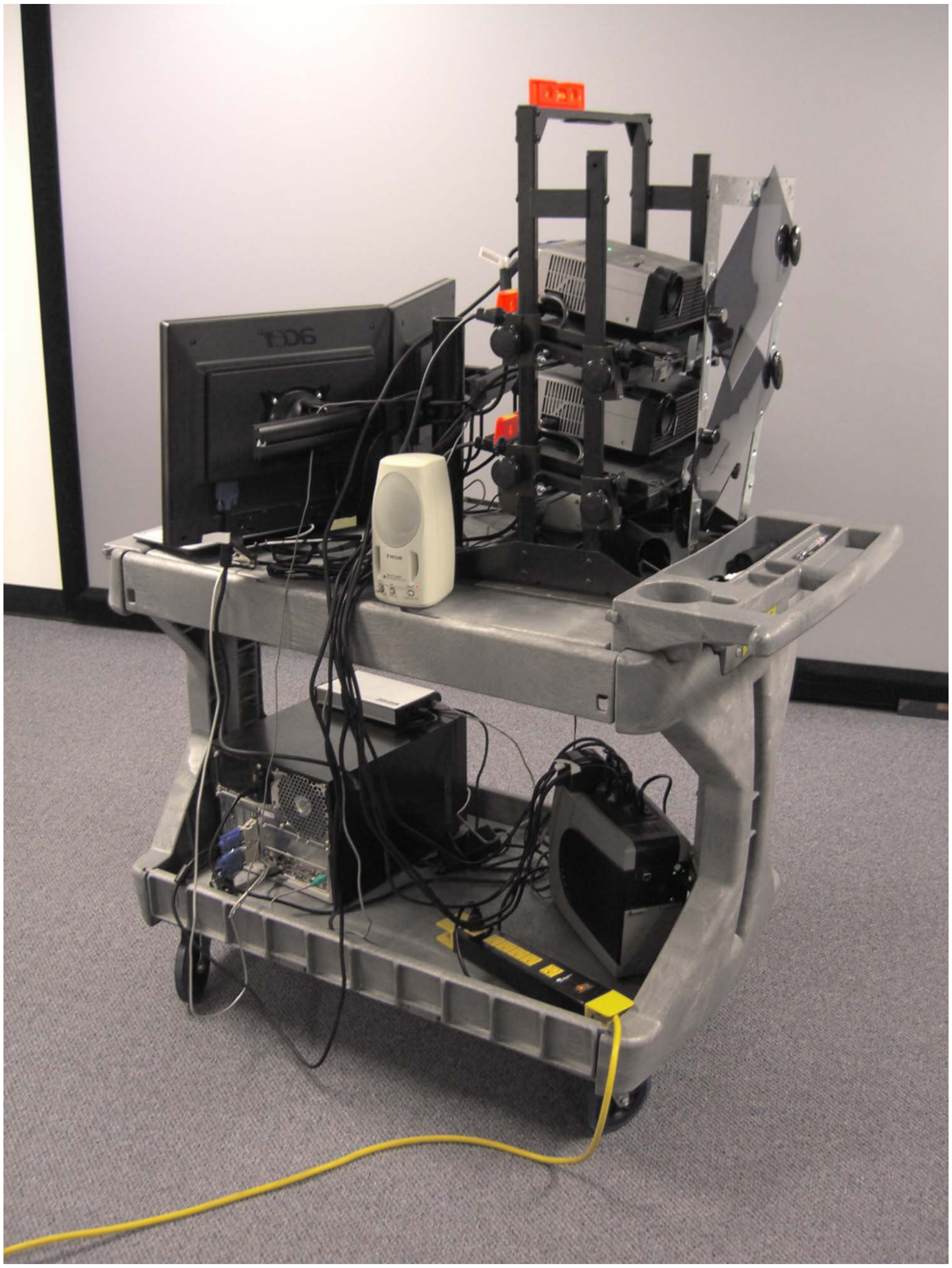

Figure 2. The portable GeoWall stereo projection system used in this study (portable silver-matted screen not shown)

2. METHODOLOGY

The target population for this study included undergraduate students taking an introductory astronomy science course. The accessible population included undergraduate astronomy students enrolled in a public university in North Texas. The sample population for this study was drawn from undergraduate students enrolled at the University of Texas at Arlington (UT Arlington), a large (>28 000 students), comprehensive doctoral/research university in Arlington, Texas (centrally located between Dallas and Fort Worth).

The method used for selecting the sample was semiconvenient. During the Fall 2008 semester, we created and conducted a Phases of the Moon Laboratory in place of the normal Moon Laboratory for the Introduction to Astronomy courses. We used all 15 intact laboratories for the four Introduction to Astronomy lectures. Students from each of the four astronomy courses are not restricted to a particular laboratory, so they enroll in whichever laboratory fits their schedule. In this manner, the laboratories retain their homogeneity. The Phases of the Moon Laboratory was created by the authors using the AstroWall software as the principle display tool. The authors conducted two approximately 2 h training sessions on how to teach the laboratory for the remaining three laboratory instructors (five laboratory instructors total).

All 15 laboratory sections used the GeoWall system using the AstroWall software, depicted in Figure 3. Eight laboratory sections were in stereo and seven laboratory sections were conducted with the exact same visuals but without stereo. The 2D laboratories used the same equipment, but one of the projectors was covered up and the students did not wear the 3D glasses. Laboratories were divided based on the following three requirements.

1. In order to reduce instructor bias, we had each instructor teach an even number of both stereo and perspective laboratories. There was only one instructor who had an uneven number of stereo and perspective laboratories because there were an uneven number of laboratories to begin with.
2. We spread the stereo and perspective laboratories out over the entire week to get rid of the day of week bias.
3. We maintained an even number of male to female instruction to get rid of gender bias. For the stereo laboratories, there were four laboratories taught by males and four laboratories taught by females. For the perspective laboratories, there were three laboratories taught by males and four laboratories taught by females.
4. We brought the equipment into the normal laboratory room in order to remove the location bias.

Because the exact same equipment was used in all laboratories (with the exception of the glasses), all students experienced the same laboratory procedure with almost the same script (the only difference was an explanation of how passive stereo works for the 3D laboratories). To reiterate, the main difference was that for one set of laboratories, the visuals were in stereo, while the other laboratories saw only 2D perspective views. We assessed student comprehension of phases of the Moon using the Lunar Phase Concept Inventory (LPCI) (Lindell and Olsen 2002). A pretest with the LPCI was given in the lecture several weeks before the laboratory and a post test was given at the end of the laboratory.

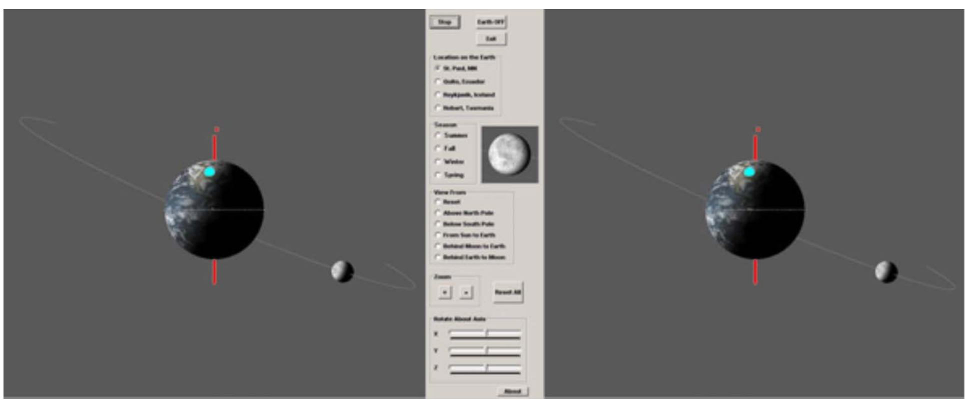

Figure 3. AstroWall display in the two-projector view as seen from the dusk side in the Full Moon phase. The white line represents the orbit of the Moon around the Earth. In this view the Sun is off screen to the left. The blue dot represents a person standing on the Earth. The red line is the Earth's rotation axis. The gray box on the right side of the left image controls the demonstration and shows the phase of the Moon as seen from an observer on Earth. The two Earth-Moon images, which are slightly offset from each other, are superposed by the GeoWall. Viewers wearing polarized glasses see the image in stereo. In the nonstereo laboratories, the right image was covered up (courtesy of http://www.geowall.org/astrowall.html)

2.1. Phases of the Moon Laboratory and Data

The AstroWall-based laboratory began at the Full Moon phase looking down on the Sun-Earth-Moon system from above the North Pole. The instructor also described the different visuals present in the display and oriented the students to the East and West directions in order to have the students understand that the Moon rises in the East and sets in the West (same as the Sun). The AstroWall display was stepped through time until the Moon reached the third quarter phase. At the third quarter phase, the time evolution was stopped. At that point, the instructor rotated the system to provide the students with different perspectives (from the dawn side, from the dusk side, view from the Sun, view from behind the Earth, view from below the south pole). After the perspective views were finished, the demonstration was returned to the view looking down on the Earth from above the North Pole. The time evolution of the visualization was started again and advanced until it reached the New Moon phase. It took 1 min for the AstroWall software to transition from phase to phase (starting with Full Moon progressing to third quarter then to New Moon then first quarter and ending with Full Moon) and 3–5 min to demonstrate the different perspective views. Starting with the third quarter phase and during the different perspective views, the students were asked a set of questions to discuss among themselves regarding the position of the Moon, rise and set times, percent of illuminated Moon seen by an observer on the Earth, etc. The same procedure was followed for the New Moon phase, first quarter phase, and then finished with the Full Moon phase. The laboratory took approximately 1 h from start to finish. Directly following the Phases of the Moon Laboratory, the students were given the LPCI post assessment.

Our operating hypothesis was that the 3D stereo image would produce a significantly larger gain in student comprehension as measured by the LPCI compared to the use of an image that shows only 2D perspective. Similarly our null hypothesis was that there was no significant gain for either 3D stereo laboratory or 2D perspective laboratory. Other studies have also examined the effect of a single laboratory or the effect of a single intervention on student understanding of a concept (e.g., Abbott *et al.* 2000).

The demographics of our sample are presented in Tables 1–3. Due to the small sizes of each group, we did not do statistics on them by group; however, we wanted to share with the reader an overview of our sample.

Table 1. Gender and major

	Males	Females	STEM Major	Non-STEM Major
2D perspective	34	41	2	73
3D stereo	51	44	4	91

Table 2. Age and classification

	18	19	20	21–25	>25	FRSH	SOPH	JR	SR
2D perspective	24	25	5	12	4	40	25	4	6
3D stereo	21	32	17	22	3	30	41	13	11

Table 3. Previous astronomy or physics course

	Astronomy	Physics
2D perspective	14	18
3D stereo	19	14

In order to determine the effect of the laboratory, we used a two-tailed, related measures, t-test. For student comprehension of lunar phases in a 3D stereo laboratory, as predicted, there was a statistically significant gain as measured by the LPCI (M_D=0.905, SD=3.346), $t_D(95)$=2.637, p=0.00978, and r^2=0.069. We also measured a statistically significant gain for student comprehension on lunar phases in a 2D perspective laboratory as measured by the LPCI (M_D=1.4, SD=3.665), $t_D(75)$=3.308, p=0.00978, and r^2=0.129. Based on the r^2 value, the 3D stereo laboratory did not have a larger effect on student comprehension of lunar phases than the 2D perspective laboratory; therefore, we could not reject that part of the null hypothesis. Thus, while the stereo AstroWall laboratories had a positive effect on student learning in a single laboratory experience, the 2D laboratories also had a positive effect and the two are not statistically different. In this case, we found that stereo visualization did not add to the educational experience.

3. CONCLUSION

Physics and astronomy are subjects in which highly spatial information is crucial to understanding concepts. For students learning physics and astronomy, it has been shown that student comprehension can be improved by reducing the cognitive load produced by mental processing of spatial relationships by representing the system with 2D perspective views (e.g., Hansen *et al.* 2004; Barnet *et al.* 2005; Küçüközer 2008; Küçüközer *et al.* 2009). In this manner, students are not forced to try to imagine the system presented to them, manipulate the system in their minds, and then try to understand concepts based (in part) on spatial relationships. However, a perspective view provides important spatial cues, and, depending on the context, 2D perspective information may be sufficient for students to deal with the material as suggested by Cockburn and McKenzie (2002). Learning about lunar phases seems to be such a case. In this study, both the 3D stereo and 2D perspective Phases of the Moon Laboratories had a statistically significant gain in student comprehension as measured by the LPCI, but the gains were not statistically different. We conclude that having a well-constructed spatial laboratory with a system that has 2D perspective visual cues would be enough to have a positive effect on student comprehension of lunar phases. Therefore, we argue that while 3D stereo displays are effective in improving student comprehension, they are not necessary to create the same amount of gain in student comprehension. The ASTROWALL software allowed us to create an easily comparable system between the two laboratories, but the stereo capabilities are not essential to produce a positive result. We suspect that other topics in introductory astronomy with a similar level of spatial complexity (e.g., seasons) also are likely to draw no significant benefit from the use of a stereo display in instruction as compared to perspective displays that are easier to create and use.

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