Visualizing Three-Dimensional Spatial Relationships in Virtual and Physical Astronomy Environments

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Abstract: Students used both virtual and physical models in a middle school lab that teaches the cause of lunar phases. Phase 1 compared two virtual models – a complex 3D model vs. a simplified 2D model. Students who used the 3D model had higher learning gains. Phase 2 compared activity sequencing. Preliminary results indicate that students with high prior knowledge benefit from using the virtual model first. Further study may confirm if this result is statistically significant.

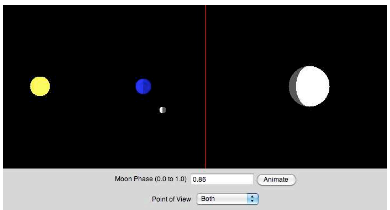
Introduction

We report on the development and testing of a "Visualization Lab," which includes both physical and virtual models, designed to teach middle school students about the cause of the Moon's phases and eclipses, phenomena that require students to visualize complex 3D relationships amongst the Sun, Earth, and Moon. The virtual component of the lab was implemented mainly in the WorldWide Telescope (WWT) computer program, an immersive astronomy data visualization environment. While visualizations hold promise for improving science education, research results on efficacy to date have been mixed. When implemented poorly, visualizations do not contribute to student learning, and in fact, students can become overwhelmed or confused, especially if the visualizations are not well-matched to student ability (ChanLin, 2001). However, Linn and Eylon (2011) cite research that suggests the tremendous promise of visualizations, when implemented correctly. Multiple studies support the idea that a blend of virtual and physical models may be more advantageous than one or the other alone (e.g. Liu, 2006). To date, little research has been done on optimal sequencing of virtual/physical models in classrooms, but Carmichael et al. (2010) have found evidence that students may benefit from using a physical model prior to the virtual model. We seek to build on this body of knowledge in our work.

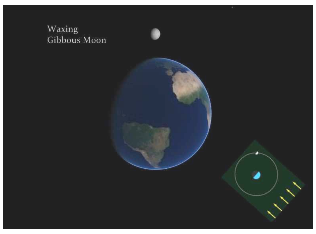
Methods, Assessment, and Results

We use a quasi-experimental method to compare different iterations of our Moon Lab. To assess student learning, we created and used identical pre- and post-tests that include multiple choice content questions about the Moon's phases, and open response questions that probe understanding of the cause of the Moon's phases. The multiple choice questions were selected from the Astronomy and Space Science Concept Inventory (ASSCI, Sadler, 2009), a compilation of distractor-driven multiple choice questions. Open-response questions embedded throughout the activities were scored using a Knowledge Integration (KI, Linn, 2000) rubric.

A. Textbook simulator



B. WWT



C. Results

		Averages (and standard deviations) Max Possible Score=7			Cohen's d
		Pre	Post	Gain	
School A	WWT	2.7 (1.2)	5.1 (1.3)	2.5 (1.3)	2.0
	TS	2.6 (1.2)	4.3 (1.4)	1.7 (1.6)	1.5
School B	WWT	2.7 (1.5)	4.4 (1.7)	1.7 (1.5)	1.1

Figure 1A. & B. show screenshots of the Textbook simulator and WWT respectively. Figure 1C. shows a comparison of average pre/post-test scores, gains, and Cohen's d effect sizes for students in School A who used WWT vs the Textbook Simulator (TS), and for students in School B who all used WWT.

Phase 1

Phase 1 used a treatment-control design to compare learning results in students who used the complex 3D visualizations in WWT as the "virtual model" vs. those who used a traditional 2D simulator. We tested the first iteration of the lab with a sixth-grade teacher at a public middle school in a suburban Eastern Massachusetts town (School A), who teaches about 80 students in four classes. Each class had one day of pre-assessment; one day of instruction with the physical model (Styrofoam ball and lamp); two days of instruction with the virtual model; then one day of post-assessment. The teacher divided her students into groups (two treatment and two control classes) with comparable student ability. The "treatment" group used WWT as the computer simulation, and the "control" group used a 2D simulator recommended by the students' textbook, and already in use by the teacher. The simulator can be found at http://www.astro.wisc.edu/~dolan/java/MoonPhase.html, which is used in Activity 81, pg. F-48, of *Issues and Earth Science* (University of California, Berkeley, 2006). We refer to the 2D visualization as the "textbook simulator" or "TS" and the 3D visualization as "WWT." Figure 1 shows sample screenshots of both the TS and WWT. Students in both Phase 1 groups (WWT and TS) showed strong learning gains (see Figure 1), but the WWT group outperformed the TS group (t-test p=0.03; N=77).

Phase 2
We tested a second iteration of the VizLab with one eighth grade teacher and 70 students at a public middle school in an urban Eastern MA city (School B). For this phase, all students used WWT as the virtual model, but we tested two different sequencing of activities: virtual, then physical; vs. physical, then virtual. The program included one day of pre-assessment; one day with the first intervention; one day with the second intervention; one day using a blend of both interventions; and one day of post-assessment. Figure 1 (third row) shows learning gains and Cohen's d effect sizes for all students in School B. The effect size measured at School B is smaller than that of both treatment and control groups at School A, but the demographics of the student populations at the two schools are very different.

We analyzed a median split of the pretest multiple choice scores and found that students with low prior knowledge benefited slightly from using the physical model first, while students with high prior knowledge benefited from using the virtual model first (see Table 1). We hypothesize that students with low prior knowledge had trouble interpreting the complex 3D computer visualization because they were not familiar enough with the mechanics of the Earth-Sun-Moon system to understand what they were looking at in the computer model. We are unsure why the students with high prior knowledge benefitted from seeing the 3D visualization first, but we hypothesize that their high level of engagement with the program could have been a factor. Further study with a larger sample size is needed to confirm the statistical significance of this result.

Table 1: A comparison of student learning gains in Phase 2.

Group	**Low prior knowledge (pretest <3)** *Average Gain (SD), N*	**High prior knowledge (pretest ≥3)** *Average Gain (SD), N*	**t-test comparing Low/High groups.**
Physical -> Virtual	Gain=2.64 (1.60), N=14	Gain=0.88 (1.58), N=17	t=3.00, p<0.01
Virtual -> Physical	Gain=2.10 (1.04), N=11	Gain=1.71 (1.16), N=17	t=0.89, p=0.38
t-test comparing model order	t=0.99, p=0.33	t=1.73, p=0.09	

Conclusions
Research shows that students of different ability learn differently from visualizations. ChanLin (2001) found that novice students with low prior knowledge learn better with static graphics, while experienced students with high prior knowledge learn equally well with dynamic visualization or static graphics. In contrast, Hays (1996) reports that middle school students with limited skill in visual processing had stronger learning gains from computer animations than from static pictures, through the use of guided explorations. Our preliminary results indicate that sequencing of virtual+physical models may need to be optimized based on student prior knowledge. Further work could illuminate how students of differing ability interact with visualizations.

References
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