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

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Overview of Study

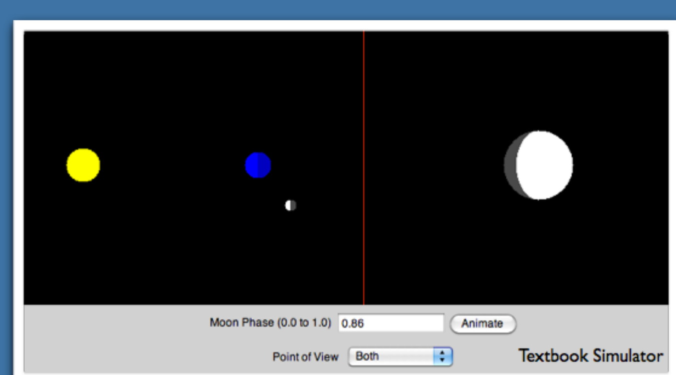
A Moon Phases Visualization Lab

We designed a middle school lab experience to help students understand the cause of the Moon's phases and eclipses, using a combination of physical models (using styrofoam balls and lamps) and computer models.

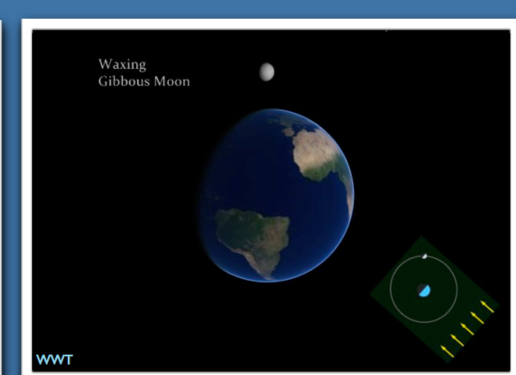
Eighth grade students using the Moon Phases Visualization Lab in an urban middle school in MA

Phase 1: 2D vs 3D computer models

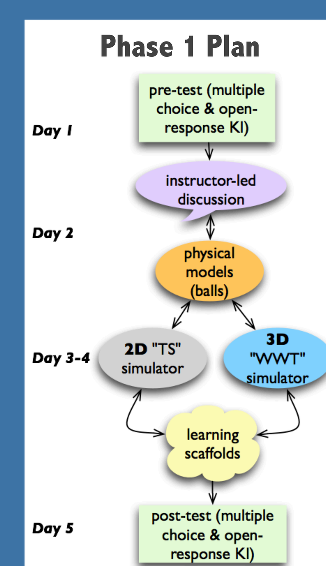
We compared learning gains from two different kinds of computer models (a simplified 2-dimensional model "Textbook Simulator" vs. a complex 3-dimensional model, WorldWide Telescope, "WWT").



2D Moon Phases simulator originally used at Phase 1 Pilot School.
http://www.astro.wisc.edu/~dolan/java/MoonPhase.html

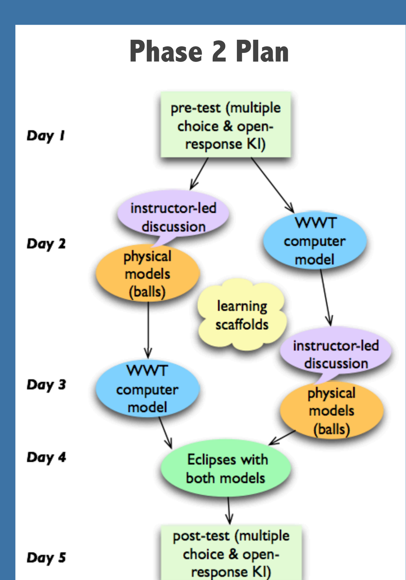


3D Visualization created in WorldWide Telescope, a free resource developed by Microsoft Research.
http://worldwidetelescope.org



Phase 2: Which model order?

All students used the 3D computer model (WWT), but half the students used the physical model first, while the other half used the computer model first.



School/Student Demographics

School X and School Y are both in the Greater Boston Area. School X is an urban school, and School Y is a suburban school.

Phase	Date	Teacher	Grade	School	N Students: Treatment 1	N Students: Treatment 2	Code
Phase 1	Nov 2012	D	6	X	$N_{Foam-TS}$=38	$N_{Foam-WWT}$=39	D12
Phase 2	Apr 2013	A	8	Y	$N_{Foam-WWT}$=40	$N_{WWT-Foam}$=28	A13
	Dec 2013	B	6	X	$N_{Foam-WWT}$=40	$N_{WWT-Foam}$=35	B13
	Feb 2014	C	6	X	$N_{Foam-WWT}$=34	$N_{WWT-Foam}$=37	C14
	Mar 2014	A	8	Y	$N_{Foam-WWT}$=42	$N_{WWT-Foam}$=38	A14

Learning Measures

- **Distractor-driven multiple choice (MC)** questions from the Astronomy and Space Science Concept Inventory (Sadler et al, 2010): 7 questions about Moon Phases and Eclipses on pre/post assessments.
- Open Response questions embedded throughout lab activities, and on pre/post assessments. Scored using a **Knowledge Integration (KI)** rubric (Linn, 2000; Linn and Eylon, 2011).

Results on Student Learning from Multiple Choice Assessments

Phase 1 Results

All students used the styrofoam ball model first. Half the students then used a 2D computer model (TS), while half the students used a 3D computer model (WWT). Students in both Phase 1 groups (WWT and TS) showed strong learning gains, but the WWT group outperformed the TS group by a statistically significant amount (t-test p=0.03; N=77). The table shows pre/post test scores on the multiple choice assessment, gain, and Cohen's d effect size.

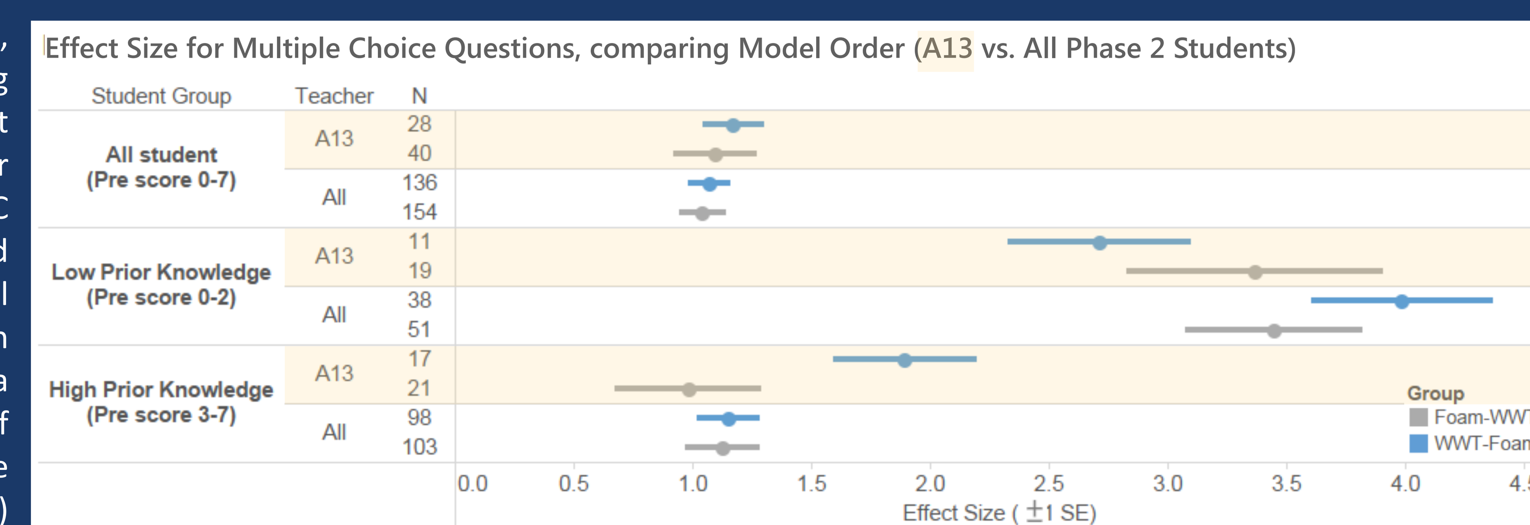
		Averages (and standard devations) Max Possible Score=7			
		Pre	Post	Gain	Cohen's d ± 1SE
Phase 1: School A	WWT	2.7 (1.2)	5.1 (1.3)	2.5 (1.3)	2.0 ± 0.2
	TS	2.6 (1.2)	4.3 (1.4)	1.7 (1.6)	1.5 ± 0.2

Phase 2 Results

Students in Phase 1 expressed such a strong preference for WWT over the TS that we were not able to find teachers willing to put half their students into a "control" group that did not use WWT. Instead, all students used WWT, but we tested the model order: Styrofoam model then WWT; vs. WWT then Styrofoam.

Pre/Post Gain Effect Sizes

In the Phase 2 Pilot (A13), we found an interesting trend indicating that students with low prior knowledge (a pretest MC score < 3 out of 7) benefited from using the Foam Model first, while students with high prior knowledge (a pretest MC score ≥ 3 out of 7) benefited from using the Computer Model (WWT) first.



We implemented the Moon Lab in classrooms of three additional teachers in the 2013-2014 school year, but we no longer see this trend when all four Phase 2 groups are combined. Instead, we see that all students show strong learning gains, with comparable effect size between the two model orders.

Regression Analysis

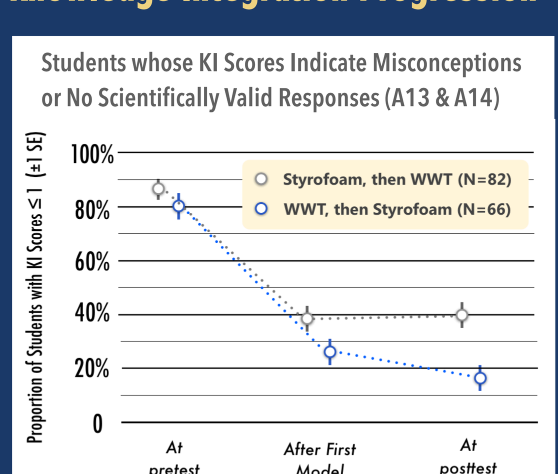
The factor that best predicts the pre-post test GAIN is the pre-test multiple choice score. As expected, students with lower pre-test scores tend to have higher gains because they have more room to grow.

Model order is a statistically significant predictor of learning gain. Students who use WWT first are expected to have a gain of 1.7, while students who use the foam model first are expected to have a gain of 1.3.

Factor	Coefficient	Probability
Pre-test MC Score	-0.50	≤0.0001
Model Order	Foam-WWT: -0.18	0.035
	WWT-Foam: 0.18	

Open Response: Knowledge Integration & Student Ideas

Phase 2 Knowledge Integration Progression



We scored open response questions using a KI progression where a score of 0 indicates no scientifically valid response; 1 indicates a response with only misconceptions; and a 2 or higher indicates a response with scientifically valid statements.

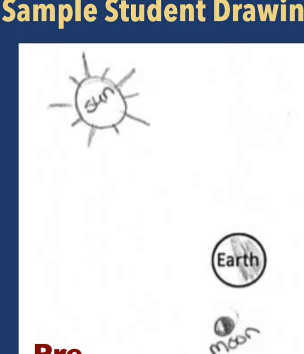
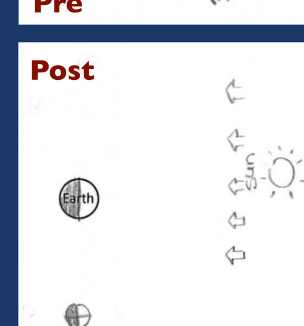
Most students (>80%) began the Moon Lab with a KI score ≤ 1, showing that misconceptions and lack of understanding are common. After using only one model, a smaller proportion of students who used WWT have KI scores ≤ 1. At the posttest, 18% of students who used WWT first have low KI scores, compared with 40% of students who used the Foam first.

Sample Open Response Question on Pre/Post Assessment

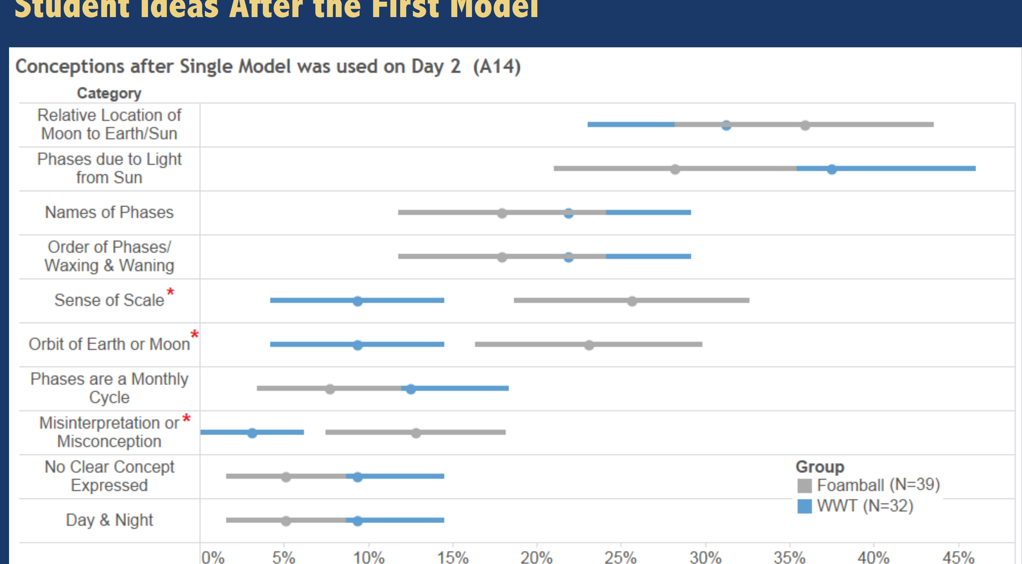
9. One day you notice a half Moon in the sky, as in this picture.

Below is a drawing of the Earth, taken from far above the North Pole. On the drawing, complete the following steps, and **check each box as you go, to show that you have completed that step.**

- ☑ Choose a location for the **SUN** and sketch it on the diagram. It's okay if it's not to scale.
- ☑ Sketch where you think the **MOON** is located relative to the Earth and your Sun, when the Moon looks like the one in the picture above.
- ☑ Label the **SUN** and the **MOON**, so we know which is which.
- ☑ Use your pencil to shade the part of the **EARTH** that would appear dark.
- ☑ Use your pencil to shade the part of the **MOON** that would appear dark.

Sample Student Drawing	Sample Student Response	Comments
 Pre	We see a half Moon on this day because: **(Pre)** *"The earth is blocking part of the moon from the sun and it casts a shadow on the moon, making half of it dark."*	Typical pre-test responses indicate that half the moon is dark because Earth is casting a shadow. This misconception would receive a KI score of 1.
 Post	**(Post)** *"We are seeing 1/2 of the lit up part of the moon. If a line is drawn on the moon to show our perspective, we see half of the light of the moon."*	This same student now presents scientifically valid ideas about a half Moon. This post-test drawing and response would receive a KI score of 3.

Student Ideas After the First Model



After Day 2, all students have only used one model (either foamball or WWT). Students shared what they learned from the first model. The chart to the left tells what proportion of students named each idea:

- ~1/3 of both groups named the important conceptual idea that the relative locations of the Moon/Earth/Sun determine the phases.
- ~1/5 of both groups named rote concepts, like the names and order of phases.

Ideas with * show a statistically significant difference between model order groups. More students who had only used the foamball:

- named a sense of scale between the Earth/Moon system as a new idea (which is critical to an accurate understanding of Moon's phases.)
- described how the Earth orbits the Sun or how the Moon orbits Earth.
- expressed misconceptions or incorrect ideas.

Student Model Preferences and Choosing Model Order

Phase 2 Model Preference

40% of all students in Phase 2 expressed a preference for the computer model (WWT), while 37% of students felt the models helped equally. Only 13% of students felt the Styrofoam model helped more.

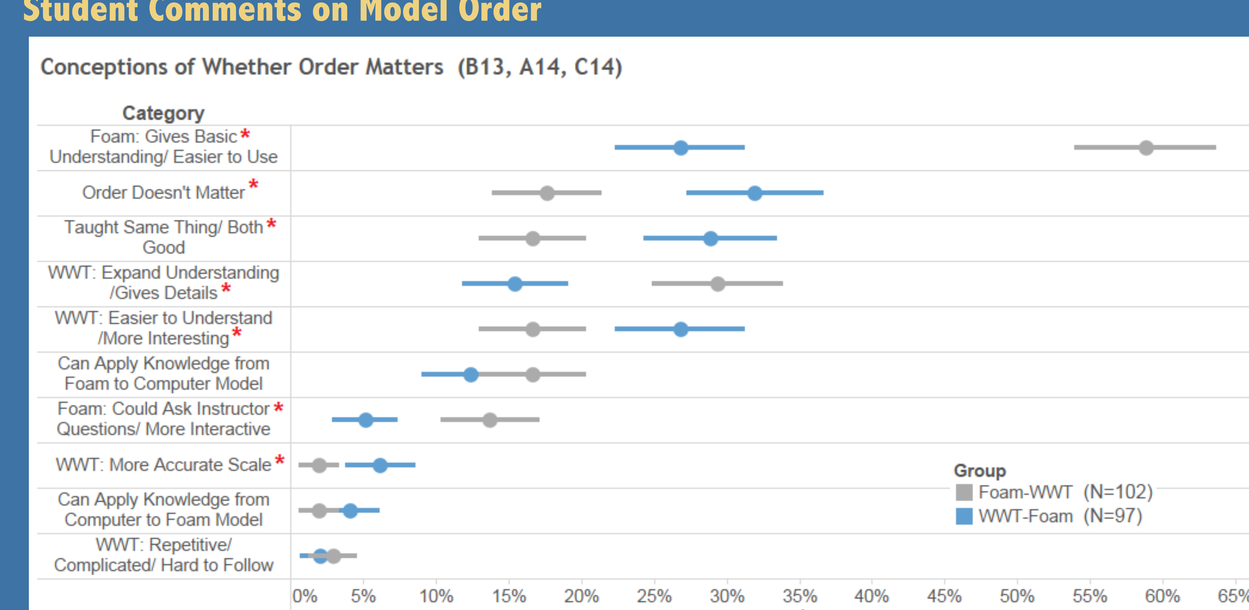
Model Preference	Proportion of Students with that Preference (All Phase 2, N=294)
Models helped equally	37% ± 3%
Computer helped more	**40% ± 3%**
Styrofoam helped more	13% ± 2%

Model Order Preference

45% of students (from 2013-2014 school year) liked having the styrofoam model first, then WWT, or wished they'd had that order. 36% said the model order didn't make a difference to them. Only 19% of students liked having WWT first, then foam, or wished they'd had that order.

Model Order Preference	Proportion of Students with that Preference (A14,B13,C14, N=212)
Model Order Didn't Matter	36% ± 3%
Like/Wish Foam->WWT	**45% ± 3%**
Like/Wish WWT->Foam	19% ± 3%

Student Comments on Model Order



The chart to the left tells what proportion of students gave each comment about model order. Ideas with * show a statistically significant difference between model order groups.

- A significant number of students expressed a preference for the styrofoam ball first because it is more basic and easier to understand.
- Many of these same students then expressed that they liked extending what they learned using the WWT-based computer model.
- Some students felt WWT was easier to understand or more interesting than the foam model.
- Some students liked getting to interact with the instructor during the foam model, (vs. the computer model, which students discussed mainly with their partners rather than the instructor).

Conclusions

- In Spring 2013, we found that level of prior knowledge may influence which model order would be more beneficial to student learning.
- After adding 3 more teacher cohorts in 2013-2014, this trend no longer holds. Performance on the MC assessment is comparable regardless of model order, with a regression analysis showing a slight benefit to using WWT first.
- For 2 cohorts where we have coded KI responses (A13, A14), students who used WWT first then the foam model expressed fewer misconceptions about the cause of the Moon's phases on the post-assessment.
- 81% of students preferred having the styrofoam model first, or had no preference about model order.
- We need to continue analyzing the KI results for the remaining 2 cohorts to determine whether there is a real benefit to student learning from using a model order (WWT->Foam) that is only preferred by 19% of students.

References

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Sadler, P., Coyle, H., Miller, J.L., Cook-Smith, N., Dussault, M., Gould, R.R., 2009. The astronomy and space science concept inventory: Development and validation of assessment instruments aligned with the K–12 National Science Standards. Astronomy Education Review 8, 010111.

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