Thinking Spatially about the Universe: A Physical and Virtual Laboratory for Middle School Science

Patricia Udomprasert, Erin Johnson, Alyssa Goodman (PI), Henry Houghton, Sonia Dalal, *Harvard University* contact: pudompra@cfa.harvard.edu
Susan Sunbury, Philip Sadler, Erika Wright, *Smithsonian Astrophysical Observatory*
Julia Plummer, Abha Vaishampayan, *Pennsylvania State University* Helen Zhang, *Boston College*

Project Overview

ThinkSpace labs teach astronomy while supporting spatial thinking skills, like imagining a scene from multiple viewpoints.

The Three Labs

1) Moon phases and eclipses
2) Seasons
3) Celestial motions within the broader universe

Sixth grade students using the hands on Foam model in the ThinkSpace Moon Phases Lab at a suburban middle school in MA.

Sample views in WorldWide Telescope. Students can explore "sky-based" images and compare them with "space-based" representations of our Cosmos. They can overlay and visualize their own data points as well. http://worldwidetelescope.org

ThinkSpace labs blend interactive computer-based astronomy visualizations in WorldWide Telescope (**WWT**) with hands-on modeling activities.

Eighth grade students using WWT in the ThinkSpace Moon Phases Lab at an urban K-8 school in MA.

WWT screenshot from the ThinkSpace Moon Phases Lab

Table 1: School/Student Demographics, 2015-2016

Districts A and B are both in the Greater Boston Area. District A is suburban, and District B is urban.

Date	Teacher	Grade	District	School	Total Students	Students Interviewed
Dec 2015	J	6	A	X	72	12
Jan 2016	K	6	A	Y	79	12
June 2016	L	8	B	Z	104	8

Model order

- Half the participating students used the foam model first, then WWT. **(Foam-WWT)**
- The other half of participating students used WWT first, then the foam model. **(WWT-Foam)**

ThinkSpace Research Questions

- *Are **spatial skills levels predictive** of students' content **learning gains** from these spatially rich labs?*
- Do students' **spatial skills** (e.g. perspective taking) **improve** after completing a **ThinkSpace Lab?**

Spatial Thinking and STEM

What is spatial thinking?

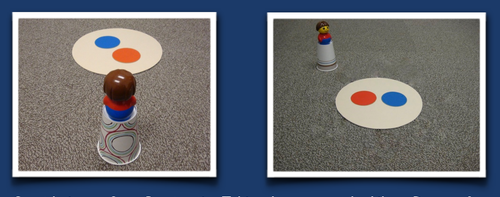
Spatial thinking combines 3 elements — "concepts of space, tools of representation, and processes of reasoning. It depends on understanding the meaning of space and using the properties of space as a vehicle for structuring problems, for finding answers, and for expressing solutions." (NRC,2006)

Spatial skills are malleable and can improve with practice (e.g. Uttal et al., 2013)

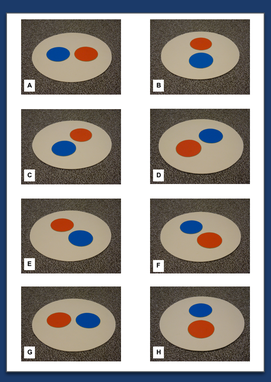
Spatial skills correlate with performance in science domains, and likelihood to enter a career in STEM (e.g. Hegarty, 2004, Wai et al. 2009)

Perspective Taking Assessment

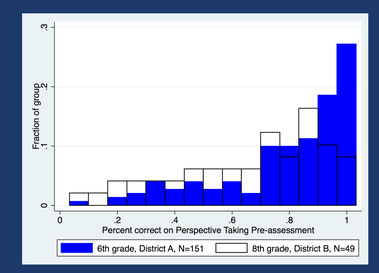
Perspective-taking: the skill of identifying how a scene might look from a viewpoint other than from one's own position or line-of-sight (Liben & Downs, 1993)



Sample items from Perspective Taking Assessment by Liben, Downs, & Bower (2015). Left: an "egocentric" view that does not require a shift in perspective. Right: a more challenging item, which requires the viewer to shift to the doll's perspective from opposite the circle and to the left.



Answer choices for indicating what the doll would see

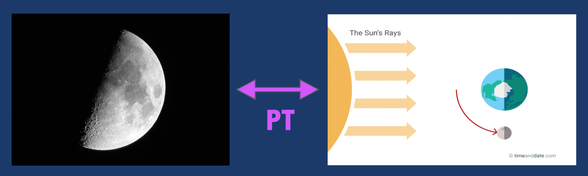


Distribution of pre-assessment Perspective Taking scores for two student groups who field-tested the ThinkSpace Moon Lab in 2015-2016.

District A students (blue) scored very well, with 46% of students getting >90% correct. Additional PT assessments are being considered to reduce this ceiling effect in the future.

District B (white) had a flatter distribution of PT scores and may show larger gains from pre-post than District A. (District B students will complete the lab and post-assessment in June 2016).

Perspective Taking and Moon Phases



Earth-based "sky view" of Moon

Space-based view of Earth-Sun-Moon System

Perspective taking (PT) in understanding lunar phases:

- Describe the phase of the Moon as it appears from the Earth (Earth-based perspective)
- Imagine the Moon illuminated by the Sun (Space-based perspective)
- Use PT to visualize which part of the lit-up Moon will be visible from the Earth

Pre-Post Interview Data

Interview Selection Process

- Subset of students (Table 1) participated in videotaped pre/post interviews where students used a model Sun/Earth/Moon to answer questions about the cause of lunar phases.
- Equal numbers of students chosen with High/Middle/Low perspective taking pre-test scores.
- Equal numbers of boys and girls chosen.

Interview Coding

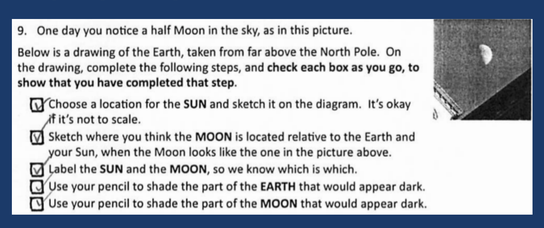
- Explicit connection between mechanism or model with the phenomenon
  1. Perspective taking: Describes how an object will look from the viewer's location and how this is explained by using the relative position of objects in space.
  2. No perspective taking: Does not use a change in perspective (viewing from a different location) in explanation.
- No connections: Does not show how the model or a mechanism can explain the phenomenon

Sample interview response that uses perspective taking:

"It'd be here may be..? <moves the model of the Moon at an angle between the Sun and the Earth> *cause the Sun is going to shine on this half* <shows the half of the Moon facing the Sun> *and you can only see some of it... here* <points to the part of the Moon which will be seen from the Earth>."

Open Response: Knowledge Integration & Student Ideas

Sample Open Response Question on Pre/Post Assessment



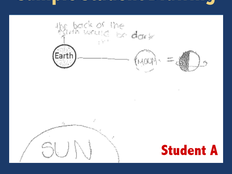
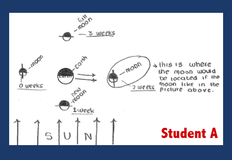
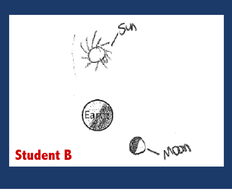
9. One day you notice a half Moon in the sky, as in this picture.

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.

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 (Linn, 2000).

Sample Student Drawing	Sample Student Response	Comments
 Student A	We see a half Moon on this day because: (Pre) "from where the Moon is, the Sun can only light up one side of it."	This correct, but incomplete explanation would receive a KI score of 2.
 Student A	(Post) "only one side of the Moon is facing the Sun, so the other side is completely dark. The person from the Earth can only see half of the bright side, cannot see the dark side.."	The same student now presents multiple scientifically valid ideas and shows how they connect. This would receive a KI score of 4.
 Student B	(Pre) "the moon is not fully covered by the Earth from the Sun's light, it is only ½, so you could see ½ of the Moon"	This misconception that lunar phases are caused by Earth's shadow would receive a KI score of 1

MOSART Data - Distractor Driven Multiple Choice Astronomy Questions

Distractor-driven multiple choice (MC) questions from the MOSART/Astronomy and Space Science Concept Inventory (Sadler et al, 2010):

- 11 questions about Moon Phases and Eclipses on pre/post assessments.
- A subset of 6 questions given after students used a single model (foam vs. WWT) as a mid-assessment to learn whether each of the two different models help students understand particular topics better than the other.

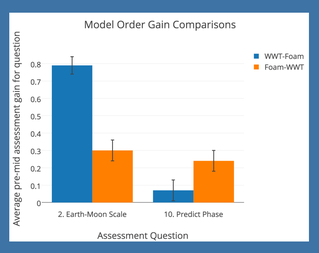
Overall Results

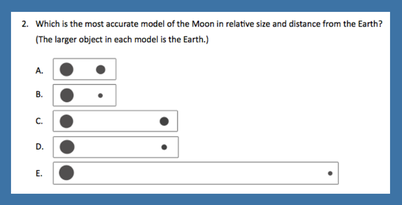
For 2 cohorts who have completed the ThinkSpace Moon lab **(Teacher J and K)**, students show significant gains for both Moon phases content and perspective taking.

- For 11 MOSART **Moon content MC** questions, Cohen's d effect size = **1.71±0.08**.
- For 15 Perspective Taking **(PT)** questions, Cohen's d effect size = **0.31±0.05** (even with 46% of students scoring ≥90% on the pre-assessment).

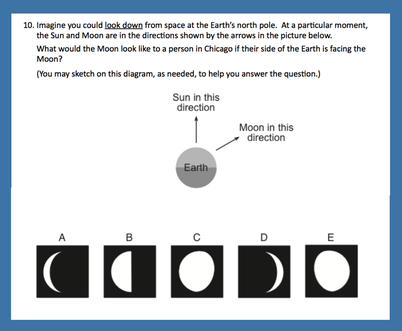
Mid-assessment Results

- No statistically significant difference in *overall* gains between WWT vs foam model on mid-assessment (after half of students used only WWT and other half used only foam model).
- Students who only used the foam model had larger gains on Question 2 regarding *Earth-Moon scale*.
- Students who only used WWT had larger gains on Question 10 that asks them to *predict what the Moon would look like when in a particular position relative to the Sun and Earth*.





2. Students who used the Foam model first had significantly higher pre-mid assessment gains on this question than students who used WWT first, indicating that a physical model is important for developing sense of scale.



10. Students who used WWT first had significantly higher pre-mid assessment gains on this question than students who used the Foam model first, perhaps suggesting that WWT helped students better connect the space-based and Earth-based views.

Next Steps

2015-2016

- Complete field testing of ThinkSpace Moon lab at School Z in June 2016.

2016-2017

- Complete development of Seasons Lab and begin testing in classrooms.
- Continue field testing of Moon Lab in additional classrooms.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. DRL-1503395.

We are grateful to partner teachers Jim Werner, Andrew Wong, Anthony Forbes, and all their students, for allowing us to field test the ThinkSpace Moon Phases Lab in their classrooms, and for offering us valuable feedback.

References

Hegarty, M., 2004. Dynamic visualizations and learning: getting to the difficult questions. Learning and Instruction 14, 343–351.

Liben, L. S., & Downs, R. M., 1993. Understanding person-space-map relations: Cartographic and developmental perspectives. Developmental Psychology, 29(4), 739.

Linn, M.C., 2000. Designing the Knowledge Integration Environment. International Journal of Science Education, 22, 781–796.

National Research Council (NRC), 2006. Learning to Think Spatially. Washington, DC: National Academies Press.

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.

Uttal, D.H., Meadow, N.G., Tipton, E., Hand, L.L., Alden, A.R., Warren, C., Newcombe, N.S., 2013. The malleability of spatial skills: a meta-analysis of training studies. Psychological Bulletin 139, 352–402.

Wai, J., Lubinski, D., Benbow, C.P., 2009. Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. Journal of Educational Psychology 101, 817–835.

wwtambassadors.org

American Astronomical Society