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

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Project Overview

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

1) Moon phases and eclipses
2) Seasons

ThinkSpace labs blend interactive computer-based astronomy visualizations in WorldWide Telescope (WWT) with hands-on modeling activities. The lessons are purposefully designed to give students opportunities to connect Earth-based views of the Sun and Moon with space-based perspectives (Plummer, Bower, & Liben, 2016).

Left: ThinkSpace Seasons Lab. Top - Students using physical models to show how Earth's tilted axis always points in the same direction while orbiting the Sun. Bottom - Students using WWT to investigate WHY cities around the globe get more hours of daylight in the summer and fewer in the winter.

Right: ThinkSpace Moon Phases and Eclipses Lab. Top - Students using physical models to observe how the phases appear to change as the "Moon" orbits around "Earth" (the students' heads). Bottom - Students using WWT to investigate how a half-lit Moon will look like a crescent from Earth when most of the lit-up side is facing away from Earth.

Context

ThinkSpace Labs were implemented at middle schools across four school districts in the greater Boston area, with eight different sixth and eighth grade science teachers from 2015-2018.

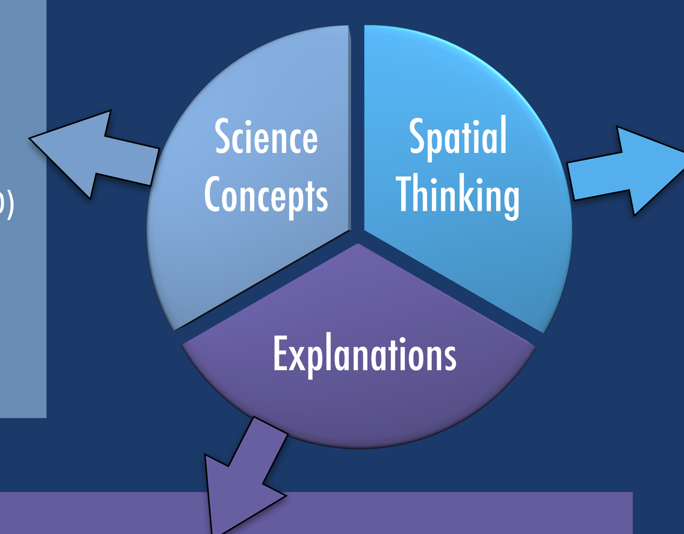
A member of the research team taught all lessons.

- Moon Phases Curriculum, N=400
- Seasons Curriculum, N=300
- Seasons + Moon Phases Curriculum, N=200
- Spatial control, N=150

Research Questions

- Did students' conceptual understanding, perspective-taking skill, and use of perspective taking during explanations improve, after participation in the curricula?
- How does a student's prior perspective-taking skill relate to a) content knowledge and b) use of perspective taking during explanations, after instruction?
- How well does perspective-taking skill predict gain in students' use of perspective taking in explanations?

Data Collection



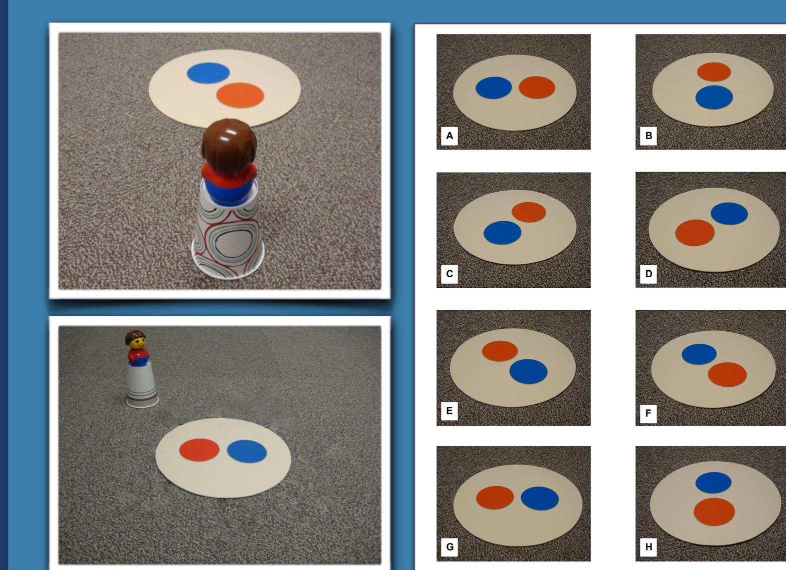
Science Concepts Assessment *(ALL students)*

Distractor-driven multiple choice (MC): ten to twelve questions from the **MOSART**/Astronomy and Space Science Concept Inventory about Seasons and/or Moon phases (Sadler et al, 2010)

Knowledge Integration: one to two open response question (Linn, 2000), where students explain their thinking in more detail and sketch diagrams to share their reasoning.

Perspective Taking Assessment *(ALL students)*

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). Top left: an "egocentric" view that does not require a shift in perspective. Bottom left: a more challenging item, which requires the viewer to shift to the doll's perspective from opposite the circle and to the left. Right: Answer choices for indicating what the doll would see.

Assessment Interviews *(subset: ~10% of students)*

In video-recorded interviews, students used a model Sun/Earth/Moon to answer questions about lunar phases and seasons. We coded for how they applied perspective taking in their explanations.

- Equal numbers of students chosen with High/Middle/Low perspective taking pre-test scores.
- Equal numbers of boys and girls chosen.

Sample student post-interview: explanation about why we see a crescent moon from Earth (boy, 6th grade)

"That side's supposed to be lit up."

"But there's still a bit of light coming back from here. You see a sliver."

"You see a crescent moon because the Earth - say there was a person right there. They would see the crescent moon."

Key Findings

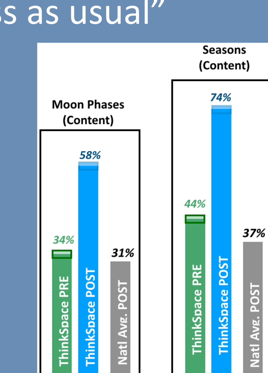
Science Concepts MOSART Assessment

- ThinkSpace students had significant pre-post content learning gains. The table below shows the Cohen's d effect sizes for the MOSART pre vs. post content scores for each lab.

	N	Cohen's d	t-test
Moon Phases and Eclipses	399	1.2, 95% CI [1.1,1.4]	t=25.5, p<.001
Seasons	293	1.5, 95% CI [1.3,1.7]	t=25.8, p<.001

- ThinkSpace students significantly outperformed a national sample of N>500 students who took the same MOSART questions following "business as usual" instruction.

*ThinkSpace Pre (**green**) vs. Post (**blue**) Content Scores for Moon Phases and Seasons, compared with National Averages of delayed post- "business as usual" instruction (N>500) from Sadler et al., 2010 (gray).*



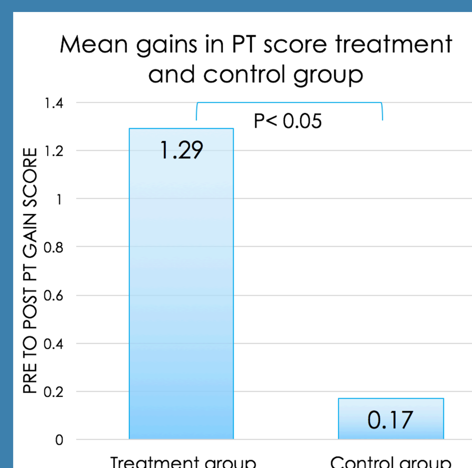
- A student's pre-test perspective-taking score is a strong predictor (p<.001) of their post-test MOSART science concepts score. Students with high spatial skills outperform students with low spatial skills.

Moon: ($F(5, 280)=32.9$, $p<.001$), $R^2 = 0.37$

Seasons: ($F(5, 309)=57.1$, $p<.001$), $R^2 = 0.48$

Perspective Taking Assessment

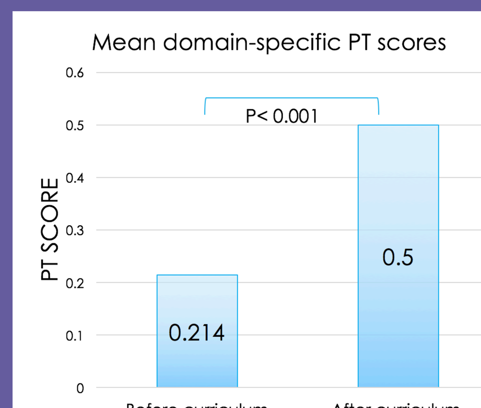
- ThinkSpace students had statistically significant pre-post gains on the perspective taking (PT) assessment.
- Control students (who did not use ThinkSpace) did not have statistically significant gains in PT score.
- An unpaired t-test shows a statistically significant difference in the PT gains for ThinkSpace vs. control students ($t(726)=-2.6$; $p=0.0049$; $d=0.27$; 95% CI[0.06,0.47]).



Assessment Interviews

- Interviewed ThinkSpace students show significant gains in their ability to accurately apply spatial reasoning in their explanations of Moon Phases and Seasons.

	N	Gain, SE	t-test
Moon Phases and Eclipses	45	0.28, 0.05	t=-7.64, p<.001
Seasons	29	0.30, 0.05	t=-4.81, p<.001

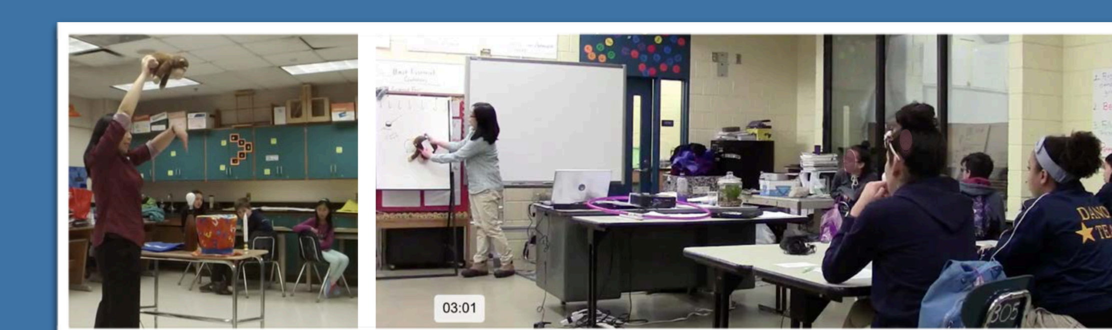


- Pre-PT skill scores significantly predict accurate use of PT before curriculum ($b=.024$, $p=.014$) and after curriculum ($b=.041$, $p=.003$)

Discussion

How did ThinkSpace curricula support students' learning to think spatially?

- Training on perspective taking was infused across their experience in the curriculum.
- Practice using perspective taking was an active part of their experience in the classroom environment, using questions and experiences that connected physical and virtual representations of astronomical phenomena.
- Spatial thinking wasn't something they passively observed; it was a skill applied to a scientific problem using perceptual and motor actions to generate mental representations.



Instructor demonstrating with a model to help students connect overhead space-based and Earth-based perspectives of the Earth-Sun-Moon system.

How do students' pre-test spatial skills impact how students learn using the ThinkSpace curricula?

- High spatial skill students made greater gains. Curricula, though helpful for both low and high spatial skill students, does not close the gap.
- Environments that provide physical and virtual support to guide spatial thinking will still help high spatial skill students over their lower spatial skill peers. We have added additional scaffolds to better support students with lower spatial skills in the final version of the Labs.

Implications

Spatial skills training can be embedded into existing curricula

- Explicitly include opportunities to practice spatial skills while students are learning about domain-specific phenomena

A backwards design approach to spatial thinking

- Begin by unpacking the central elements of spatial thinking and design opportunities for students to practice these skills, while they are also making sense of central phenomena

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References

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.

Plummer, J. D., Bower, C. A., & Liben, L. S. (2016). The role of perspective taking in how children connect reference frames when explaining astronomical phenomena. International Journal of Science Education, 38(3), 345-365. doi: 10.1080/09500693.2016.1140921

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.