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The Role of Perspective Taking in How Middle School Students Explain Lunar Phases

Abha M. Vaishampayan, Pennsylvania State University
Julia Plummer, Pennsylvania State University
Kyungjin Cho, Pennsylvania State University
Patricia Udomprasert, Harvard University
Erin Johnson, Harvard University
Susan Sunbary, Smithsonian Astrophysical Observatory
Henry Houghton, Harvard University
Erika Wright, Smithsonian Astrophysical Observatory
Helen Zhang, Boston College
Alyssa Goodman, Harvard University

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Subject/Problem

Spatial thinking is central in developing expertise across different scientific disciplines (Wai, Lubinski, & Benbow, 2009). Longitudinal studies relating early measures of spatial skills to future educational and occupational outcomes also point to the importance of spatial thinking in students' future success in science (Wai et al., 2009). According to the National Research Council (NRC) report *Learning to Think Spatially* (2006), foundations of spatial thinking lie in the relationship between concepts of space, tools of representation, and processes of reasoning. Spatial thinking encompasses processes that require spatial skills, such as changing perspectives, imagining changes in scales and creating representations of our mental imagery. For example, geologists reason about physical processes behind formation of terrestrial structures such as faults and mountains; engineers design products by initially visualizing them from different perspectives; and chemists study chirality to develop models of molecules. All of these tasks require spatial thinking, but that spatial thinking is unique to each domain (NRC, 2006).

Therefore, a domain-specific approach to studying spatial thinking is important. In this study, we focus on the role of spatial thinking in how children learn astronomy as this is a highly spatial domain but one with little research on how children reason spatially (NRC, 2006; Author et al., 2016). Wilhelm and colleagues (2013) found that middle school students' performance on written assessment of lunar phases was positively correlated with mental rotation skill. They also found that participation in a space science curriculum improved students' mental rotation skill as well as spatial thinking in astronomy. A recent study by Author and colleagues (2016) explored the connection between *perspective-taking* (PT) skill, as measured by a paper-pencil task, and the nature of students' explanations of celestial motion phenomena. Perspective taking is the skill to identify how a scene might look from a viewpoint other than from one's own position or line-of-sight (Liben & Downs, 1993). Changing perspective entails imagining a new point of view in an environment or taking a new point of view on an object. Explaining celestial motion phenomena requires understanding of different perspectives along with constantly shifting between space-based and Earth-based perspectives (Author et al., 2016). Author et al. (2016) found that, in a small sample of 7-9 year olds (N=15), children with a higher skill of perspective taking made more explicit connections between Earth- and space-based perspectives in their astronomical explanations.

Research on relationships between individuals' spatial skill and their understanding of astronomy may help explain why some learners are more adept at constructing astronomical explanations than others. In this research study, we investigated how students used PT in communicating their understanding of lunar phases. Explaining lunar phases requires learners to first describe the phase of the Moon as it appears from Earth (Earth-based perspective), then imagine the Moon illuminated by the Sun (space-based perspective) and use PT to visualize which part of the Moon will be visible from the Earth to explain their observation by connecting these two reference frames. Our study is guided by the following research questions:

1. Is PT skill correlated with how students demonstrate connections between Earth- and space-based perspectives when explaining lunar phases?
2. Does students' use of perspective taking when explaining phases of the Moon improve through a curriculum designed to support students' use of multiple perspectives through physical and virtual models?

3. What are the qualitative differences between explanations that accurately use perspective taking when explaining lunar phases and those that do not?

We chose to investigate lunar phases because a) this astronomical phenomena is commonly taught in many K-12 schools and b) as an example of a celestial motion phenomena, results of this analysis may be relevant to understanding spatial thinking across the broad range of astronomical phenomena in K-12 standards.

Design/ Procedure

The study took place in two high SES middle schools outside of a large urban area. Four classes of 6th grade students participated in a three-day lab designed by the research team to support spatial thinking as they learned about lunar phases and eclipses. The lab blends physical and virtual models of 3-dimensional astronomical phenomena. Physical models gave students the opportunity to learn about lunar phases by enabling them to manipulate different positions of the models of celestial bodies; while the virtual models allowed students to change their perspective and visualize the changes in lunar phases with the help of a computer simulation.

Two types of data were collected: PT task scores and pre/post interviews. The PT task is a battery of 15 items that measures students' PT skill (Liben, 2012). Students were purposefully sampled to be interviewed across the entire range of PT task scores. An interview protocol was developed to elicit students' explanations for the lunar phases. Photos of Moon phases and foam models of the Sun, Moon and Earth were provided to enable students to demonstrate their explanations. All the interviews and classroom instruction were video recorded for interpretation and coding.

We developed a codebook to categorize how students used PT when explaining lunar phases. The codes were organized into two categories based on use of perspectives when explaining lunar phases: *Multiple Perspectives* (connections between multiple perspectives when perspective taking) and *Single Perspective* (descriptions of single or disconnected perspectives). Three codes were included under *Multiple Perspectives*: (1) Multiple Perspective Taking-Accurate (MPTA): The student shows how the Moon is lit up by the Sun and how that connects to which phase we would see from the Earth. Response suggests that the student is accurately visualizing the way in which the Moon is illuminated in space and what portion of that illuminated sphere would be seen from the Earth. (2) Multiple Perspective Taking- Inaccurate (MPTI): The student shows how the Moon is lit up by the Sun, but does not associate the Moon's location in its orbit with the correct phase. (3) Multiple perspective taking - General (MPT): The student connects Earth- and space-based perspectives in explanation but the response does not reveal whether their connections are accurate. The *Single Perspective* category included: (1) Earth-based perspective: Description of view from the Earth; also called as the egocentric perspective (for the question about seeing Earth from the Moon). (2) Space-based perspective: Description based on viewing space from a random location in space. A third category included a single code, *Blocking Mechanism*: Explains phase(s) using the earth's shadow or blocking. Students were coded for each of the interview questions separately (see Table 1 for an example).

Two authors of this proposal coded 25% of the pre/post interviews (n=10) independently to determine Cohen's Kappa coefficient for inter-rater reliability. The results of our interrater analysis was Kappa = 0.783 with $p<0.001$. This agreement is statistically significant and, according to Landis and Koch (1977), counts as substantial agreement. We used SPSS to calculate Pearson's correlation coefficient to analyze the correlation between PT skill and students' use of MPTA when explaining lunar phases. For the purpose of analysis, each instance when a response was coded as 'MPTA' was given a weighted value. All the other instances were given a value of 0. For example, a student whose answers were coded as MPTA for 5 out of 6 interview questions, was given a score of .83. We used a paired two-tailed test to analyze whether students' use of MPTA (using the same fractional calculation of MPTA) improved after the 3-day instruction. A qualitative analysis was carried out to study the difference between the responses of those who connected multiple perspectives and those who did not.

Table 1. Simplified versions of interview questions and an example of a pre/post response codes.

Student ID	Why do we have lunar phases?	Repeating pattern of phases?	Explain the crescent Moon?	Explain the half Moon?	Explain the full Moon?	Explain the new Moon?
Black Hole 1123 Pre	MPTA, blocking, MPTI	Blocking, MPTI, PT: Earth, PT: Space	MPTA	MPTA	MPTI	Blocking
Black Hole 1123 Post	MPTA	PT: Space	MPTA	MPTA	MPTA	MPTA

Analysis/Findings

Correlation between PT skill and accurate use of multiple perspective taking when explaining lunar phases. A Pearson correlation coefficient was calculated to analyze the relationship between students' PT skill and use of MPTA in answering questions about lunar phases. Before instruction, a positive correlation was found ($r(18) = .443$, $p<0.05$), indicating a significant relationship between PT skill and use of MPTA. Similarly, we found a positive correlation between the variables after instruction ($r(18) = .631$, $p=0.001$). This suggests that students with high PT skill tend to provide the most accurate connection between how lunar phases appear from Earth and where the Sun-Earth-Moon system will need to be to produce this observation. This points to a connection between the abstract spatial skill of *perspective taking* and the domain-specific ability to explain astronomical phenomena by connecting multiple perspectives.

Improvement in how students connect multiple perspectives after spatial thinking curriculum. We analyzed the interviews using a paired t-test to see whether students use of MPTA increased when explaining lunar phases after the instruction. Students' mean MPTA score increased significantly, from 0.27 (SD=.35) on pre-interviews to 0.74 (SD=.28) on post ($t=-2.693$, $p<0.001$). This suggests that instruction may have supported students' ability to accurately connect Earth- and space-based perspectives when explaining lunar phases.

Qualitative differences between explanations that accurately use perspective taking when explaining lunar phases and those that do not.

We found that the majority of students, both before and after instruction, were coded with multiple codes across the interview (Refer to table 1). For the purpose of illustration, we show the differences in responses by discussing the pre-interview of 1123 Black Hole[1]. When asked why we see a crescent moon, her MPTA response was: "Because the Sun is going to be shining on *this* part of it [shows the half of the Moon facing the Sun]. But if you're looking from the North pole, you can only see [points to a part of the Moon], cause it's shining this way and you can only see *that* much of it [shows a part of the Moon visible from the Earth], like a little bit of

[1] All names of the interviewees are pseudonyms

it." This response was coded as MPTA because it provided explanations that demonstrated her understanding of how light illuminates a sphere (the Moon) and how that sphere would appear from the Earth-based perspective.

MPTI responses differed in that; while students made connections between what they observed from the Earth (the appearance of a lunar phase), and how the Moon is illuminated in space, the explanation revealed that their understanding of how the Moon is lit up by the Sun is non-normative. When asked about the full Moon, Black Hole placed the Moon at a gibbous position and explained, "Because the Sun is going to shine on this side, […] it's gonna light up half of it, which is going to be a maximum out. But also when you're looking from the North pole, you're going to look at it this way [gestures an imaginary line between Earth and Moon] which means that you can see all of the lit up side." In her explanation, she connects the two perspectives by visualizing how the Moon would look like from the North pole but she incorrectly places the full Moon in a gibbous position.

The other non-normative category of explanation where students still used the concept of light from the Sun as part of their explanation was *Blocking*, as has also been discussed in several previous studies (e.g. Baxter, 1989). For example, when asked why we see new Moon, Black Hole explained, "Because the Earth is blocking the light from the Sun, which causes the Moon not to be able to light up, because there's no light to go to it."

By looking across students' interview responses, we found patterns in how students were coded using multiple and single perspectives when explaining lunar phases. When we analyzed the sample of students who used blocking mechanism in their pre-interviews, we observed that majority of them answered the other parts of the interview using single perspective. They were able to explain how the sphere of the Moon is being illuminated by the Sun (PT: Space) but they did not connect it to how that explains what they would see from the Earth (PT: Earth). Their explanations were limited to using the models to show the positions of the Moon, Earth and the Sun without any connections. This suggests that these students are primarily relying on a space-based perspective; the blocking mechanism does not require them to perform any complex mental visualizations.

One of the questions from the interview protocol was aimed at understanding whether the students are able to explain the repeating pattern of the lunar phases. Those students who gave combined responses such as blocking + MPTI, did not explain the lunar phases as a cycle. In other words, when asked about individual phases, they were able to provide a reason for why we see them, even though their reasons were non-normative. But they struggled to explain the sequentially changing pattern of waxing and waning phases using the Moon's orbit around the Earth. On the other hand, those coded as MPTA could accurately show waxing and waning lunar phases as a complete repeating cycle, as part of their explanation, involving the Moon's orbit. This suggests that even though students know that lunar phases appear as an effect of the geometry of the Sun, Moon and the Earth, many students lack spatial thinking about the system.

Black Hole used MPTA to explain the crescent and half Moon phase, and also in her pre-interview, used blocking mechanism to explain the new Moon and the full Moon. This discrepancy may have occurred because of her lack of knowledge about the Moon's tilted orbit that prevents it from being blocked by the Earth's shadow. This further reinforces that spatial thinking, unlike spatial skill, is always contextualized; and that the content knowledge of a specific discipline is necessary to support our spatial thinking.

Contribution

Spatial thinking is important in many STEM domains and spatial skills are predictors of success in science (Hegarty, 2014). Our findings add to a growing body of research suggesting that having a particular set of spatial skills is required to gain expertise in different science domains. We found that students with high PT skills were more likely to make accurate connections between the Earth and space-based references frames to explain lunar phases. As astronomical phenomena such as the seasons and the orbits of exoplanets, require a learner to visualize celestial motion by transforming reference frames, the findings may contribute to our understanding of how students learn across the domain of astronomy.

There has been limited research on how instruction improves spatial thinking in astronomy (Author, 2014). Recreating astronomical phenomena in a classroom setting, in ways that support students in considering both an Earth- and space-based perspective, is a challenging task. Students in this study improved significantly in how they accurately connected multiple perspectives in explaining lunar phases. This suggests that students' experience in the curriculum using a combination of virtual and physical models that engaged them in making these connections supported this type of perspective taking. Teaching spatially challenging topics with the help of physical and virtual models that enable students to visualize and think spatially about complex phenomena may be useful across other science domains. Further, comparison of the different approaches students took to explain lunar phases supports importance of considering spatial thinking as requiring a combination of both the content of astronomy and spatial skill of perspective taking. Students who could provide accurate multiple perspective taking responses also used their understanding of the Sun-Earth-Moon system in a scientific way; those who used blocking or other inaccurate methods did not. This highlights the importance of instruction that emphasizes systems thinking in astronomy as a way of supporting spatial thinking. Our next step is to analyze the classroom videos using perspective taking as a lens to interpret how the students interacted with the models towards understanding how the instruction helped a) engage them in perspective taking and b) support their use of systems thinking.

General Interest

The research study discussed in this proposal highlights the importance of spatial thinking which is often ignored as an element in enhancing student achievement in science education. Our methods and findings will be of interest to NARST members who are interested in studying spatial thinking in domains other than astronomy.

References

Hegarty, M. (2014). Spatial thinking in undergraduate science education. *Spatial Cognition & Computation*, *14*(2), 142-167.

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

Liben, L. S. (2012). *A photographic perspective-taking task*. Unpublished measure, Cognitive and Social Development Lab, Pennsylvania State University.

NRC. (2006). Learning to think spatially. Washington, DC: National Academies Press.

Wilhelm, J., Jackson, C., Sullivan, A., & Wilhelm, R. (2013). Examining differences between preteen groups' spatial-scientific understandings: A quasi-experimental study. *The Journal of Educational Research*, *106*(5), 337-351.

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*(4), 817.