Thinking Spatially: Improving Middle-school Students' Use of Perspective Taking Through an Astronomy Curriculum

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Subject/Problem

Research has shown that having strong spatial skills is foundational in predicting students' performance in science, technology, engineering and mathematics (STEM) education (Wai et al., 2009). A meta-analysis of 217 studies was carried out by Uttal and colleagues (2013) to understand the effects of training on improvement of spatial skills. They found that spatial skills are malleable and that spatially enriched instruction may increase students' achievement in STEM fields. However, most of these studies included domain-general training rather than discipline-specific instruction for improving spatial skills and spatial thinking.

A few studies on improving spatial thinking in STEM disciplines have been carried out using discipline-specific classroom instruction. Hsi, Linn and Bell (1997) found that strategies, including paper-based exercises, hands-on block construction, and computer-based activities, improved students' competence in engineering graphic design. Hsi et al. (1997) also found that instruction in strategy selection can help students identify when to use strategies. Sorby (2009) investigated students trained to develop 3D skills through multimedia software modules that facilitated the same tasks. However, Sorby found that sketching was the most effective way in determining students' 3D spatial skill. Kozhevnikov and Thornton (2006) found that undergraduate students' level of spatial visualization ability in physics was improved significantly by spatial training through computer-based laboratory. Wilhelm et al. (2013) examined students' spatial reasoning as they participated in Earth/Space content units through two different curricula. While the study did not discuss the use of explicit spatial skill training, they found significant improvement in some areas of spatial thinking among female participants.

These are some of the few studies showing how classroom-based instruction can improve spatial skills in STEM disciplines. However, most of these studies are limited to undergraduate education. Little research exists, outside the work by Wilhelm and colleagues, in the context of middle or high school. Therefore, we investigated a curriculum designed to engage students in explicit, domain-specific spatial training, which we hypothesized would improve spatial thinking in the domain of astronomy. The curricular focus was lunar phases, a phenomenon commonly taught in middle-school science curricula. Explaining this phenomenon relies on the use of perspective taking, which we chose as the focus of our curriculum's spatial skill training.

Perspective-taking (PT) skill is defined as the ability to determine how a scene might look to an observer from a different perspective or a different line-of-sight (Liben & Downs, 1993). Second author and colleagues (2015) found a relationship between students' PT skill and how students engage with spatially complex astronomical phenomena such as apparent motion of the Sun and the stars and seasonal changes in constellations. Understanding lunar phases requires an observer on Earth to make connections between a space-based perspective and an Earth-based perspective. First, the observer must visualize how the Moon is being lit up by the Sun (space-based perspective) and then imagine which part of the lit-up Moon would be visible to an observer on the Earth, depending on the position of the Moon with respect to the Earth. Thus, PT skill is useful in understanding the mechanism of lunar phases. Therefore, instruction for teaching lunar phases was designed to leverage students' PT skill by engaging them in spatial tasks using multimodal ways of learning. For the purpose of this study, we focus on the following research questions:

1. To what extent does students' perspective taking improve after the *ThinkSpace* Lunar Phases curriculum?
2. How well do perspective taking skill and gender predict accurate use of perspective-taking while explaining lunar phases, before and after the *ThinkSpace* curriculum?
3. How well do perspective-taking skill and gender predict gain in accurate perspective taking performance, after the *ThinkSpace* curriculum?

Design/Procedures

Study Context and the *ThinkSpace* Lunar Phases Curriculum: The study took place in four middle schools in a large urban and suburban school district in New England over a period of two years. A total of 329 sixth and eighth grade students (ages 11-13 yrs) participated in the *ThinkSpace* Lunar Phases curriculum, designed to teach lunar phases and related concepts. The three-day curriculum was taught by a member of the research team. Implementation was video recorded in at least one classroom in each school, allowing for a detailed record of opportunities provided to students to engage in perspective taking.

The three-day *ThinkSpace* lunar phases curriculum was designed to give students opportunities to use physical and virtual models to learn about lunar phases and to develop domain-specific spatial thinking. Instruction was specifically designed to support students' use of PT in multimodal ways - by using toys as props to explain the PT skill, using physical models of the Sun, Moon the Earth, and using virtual models on World Wide Telescope (WWT) - a computer-based visualization interface that combines telescopic imagery with three-dimensional computer modeling to allow users to explore astronomical phenomena.

Day 1: The teacher modeled PT-skill by changing positions of different randomly-shaped objects with respect to each other in the classroom space. The teacher then connected this to lunar phases by explaining how visualizing lateral and overhead views is important in understanding the mechanism behind lunar phases. Additionally, the teacher introduced students to virtual models of the system of the Sun, Moon and the Earth, which were scaled appropriately to visualize distances and sizes of celestial bodies with respect to one another. This step was important in understanding lunar phases, especially because the physical dimensions like shape, size and distance of the celestial bodies affect how the Moon is illuminated and how it looks different depending on the perspective of an observer on Earth.

Day 2: The teacher provided physical models of Sun, Moon and Earth to the students to emphasize the connection between a space-based view and an earth-based view. Students themselves acted as the Earth while holding a Moon ball in their hand against a light source and identified parts of the Moon that are visible to the viewer on Earth if viewed from different perspectives. The noticeable difference between the PT activity on Day 1 and Day 2 was the transition from using random objects, to learn general concepts of PT, to focusing on understanding PT related to spherical bodies, which supports reasoning about lunar phases. Using physical models of the objects created agency for students to train themselves to use their PT skill to identify lunar phases. The teacher also showed a strategy to connect the perspectives by drawing a 2D representation of the phenomenon of lunar phases. She showed how to draw a 2D diagram by taking into consideration the parallel light from the Sun lighting up the Moon, then imagining a space-based view to determine which side of the Moon is lit up, and then determining an Earth-based view. Students were then given the opportunity to apply this strategy and further train their PT skill as they solved worksheets while using WWT. This graphical representation supports students' visualization in understanding lunar phases and using PT.

Day 3: The teacher began instruction by asking students questions to help them make connections between the two perspectives by using their PT skill. She first modeled the accurate connections between different perspectives and then continued asking questions in order to elicit students' PT skill. The teacher gave students opportunities to identify all the different phases by using their PT skill. In summary, the teacher supported students' use of PT through different teaching strategies in multi-modal ways of engaging with the phenomenon of lunar phases.

Data Collection: Before and after instruction, students were given a general PT skill task: a battery of 15 items that measures students' PT skill (Liben, 2012). To control for the possibility of test-retest improvement, this same task was given to a control group of 107 middle school students over the same time span as the treatment group; the control group did not participate in the *ThinkSpace* curriculum or any other spatially-oriented curricula during that time.

The data for this study comes from the sample of students who were interviewed before and after instruction. These students (N=45; 26 male, 19 female) were purposely sampled to represent the range of PT task scores. An interview protocol was developed to elicit students' explanations for lunar phases. Photos of Moon phases and foam models of the Sun, Moon and Earth were provided to enable students to demonstrate their explanations during interviews. Interviews were video recorded for interpretation and coding.

Analyses/Findings

Analysis: Student interviews were coded to assess how students used PT when explaining lunar phases. The main code of interest for the present study was: Multiple Perspective Taking- Accurate (MPTA): The student uses the models to show how the Moon is illuminated by the Sun and connects this perspective to the phase a viewer 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. Other codes included: inaccurate use of multiple perspective taking, Earth-based perspectives, space-based perspectives, and use of the shadow or blocking mechanism to explain the phases. For the present study, we numerically represented students' fractional use of MPTA during the interview, with each instance coded as 'MPTA' given a weighted value. All the other coded responses were given a value of 0. For example, a student whose answers were coded as MPTA for 4 out of 6 interview questions and inaccurate MPT for the other two questions, was given a score of .67.

Improvement in students' use of MPTA was analyzed using a paired-samples t-test. To calculate improvement using the general PT task, gain scores were compared between the *ThinkSpace* cohort and control group using an independent samples t-test. This controlled for improvement due to repeated testing. The relationships between students' pre-MPTA weighted scores, post-MPTA weighted scores, and gains scores with other variables (gender, PT score) were analysed using multiple regression analyses. The purpose of the regression analysis was to analyze potential associations between independent and dependent variables.

Research question 1: To what extent does students' use of perspective taking improve after the ThinkSpace curriculum?

We analyzed improvement in students' use of PT in two ways. First, we considered how they improved in their *application* of PT skill in explaining lunar phases during the interviews. Students were significantly more likely to use MPTA when explaining lunar phases after instruction, than before instruction ($t(43)=-6.117$, $p<0.001$). Before instruction, the average score for MPTA was .214 (SD=.259). After instruction, this improved to .50 (SD=0.339). In other words, students made more accurate use of perspective-taking in their lunar phases explanations after participating in the *ThinkSpace* curriculum.

We also measured students' improvement in their domain-general use of PT, as measured by the PT task (Liben, 2012). Students who participated in the ThinkSpace curriculum made significant improvement in their PT skill, when compared to a similar group of middle school students who did not participate in the curriculum ($t=2.801$, $p<.01$). Students in the ThinkSpace condition (N=42) improved by 1.29 (SD=2.68) compared to the control group (N=127) improvement of 0.17 (SD=1.96). This suggests that participation in the *ThinkSpace* curriculum improves the general spatial skill of PT.

Research question 2: How well do perspective taking skill and gender predict accurate use of perspective-taking while explaining lunar phases, before and after the ThinkSpace curriculum?

To investigate how well perspective-taking scores and gender predict MPTA performance, a separate multiple regression was conducted for both pre-MPTA performance and post-MPTA performance as the dependent variable. The model explains 10.5% of the variance in pre-MPTA scores ($F(2,41)=3.529$, $p=.039$, adjusted $R^2=.105$), but only PrePT significantly predicts pre-MPTA score (Beta=.024, $p=.014$). Gender did not contribute to the multiple regression model. PrePT is moderately correlated with pre-MPTA ($r=.366$, $p=.007$).

The model explains 12.7% of the variance in post-MPTA scores ($F(2,41)=4.131$, $p=.023$, adjusted $R^2=.127$), but only prePT significantly predicts post-MPTA score (Beta=.041, $p=.003$). Gender did not contribute to the multiple regression model. PrePT is moderately correlated with post-MPTA ($r=.409$, $p=.003$). These findings suggest that students with higher PT skill are more likely to use PT when explaining lunar phases, both before the *ThinkSpace* curriculum and after the curriculum.

Research question 3: How well do perspective-taking skill and gender predict gain in accurate perspective-taking performance, after the ThinkSpace curriculum?

We investigated whether the *ThinkSpace* curriculum would preferentially improve students' MPTA scores based on their PT skill or gender. To investigate how well perspective-taking scores (prePT) and gender predict gain, a multiple regression was conducted for gain as the dependent variable. PrePT and gender are not significant predictors of gain on PT performance when explaining lunar phases. A similarly non-significant result was found for PostPT score. Thus, participation in the *ThinkSpace* curriculum appears to improve students' application of PT skill to explaining lunar phases equally across levels of PT skill.

Discussion/Contribution

Even though there is enough evidence of how spatial skills are predictors of achievement in STEM fields, there is a lack of literature about how to foster students' spatial skill through training (Stieff & Uttal, 2015). Lowrie and colleagues (2017) argued that current spatial interventions are unlikely to have any impact on curricula as the training is not embedded within classroom practices. Therefore, through this research study, we investigated the role of instruction embedded in the classroom practices on developing perspective taking in understanding lunar phases. We found that instruction focused on training perspective-taking skill improved students use of PT in their explanations of lunar phases. In addition to that, students who participated in the lunar phases curriculum also improved their domain-general PT skill. We argue that explicit ways of teaching PT through multi-modal activities and embedding spatial skill training in the curriculum itself may have played a role in improving students' application of PT to their conceptual understanding. This finding also suggests that including discipline-specific instruction and training about spatial skill can be useful in developing overall discipline-specific knowledge and spatial thinking.

We also found that students with higher PT skill are more likely to give accurate explanations for lunar phases both before and after instruction. Even though we studied PT skill and its application in the domain of astronomy, this finding further supports research that spatial skill is a predictor of students' performance in STEM fields (Wai et al., 2009). In our case, students' PT skill seems to be the predictor of students' ability to accurately understand lunar phases, as has been found for other celestial motion phenomena (Author2 et al., 2015). However, students who participated in the *ThinkSpace* curriculum showed no significant difference in gain, depending on their PT skill. In other words, the *ThinkSpace* curriculum favored all the students equally irrespective of their spatial skills before and after instruction. Thus, more research is needed to find ways to help students with lower spatial-skills catch up with their higher spatial-skill peers.

In summary, this study contributes to the limited literature that exists about domain-specific instructional training of spatial skills and its application in understanding conceptual knowledge. Our findings suggest that to improve spatial thinking in a specific STEM discipline, educators should begin by identifying those aspects of spatial thinking central to reasoning in that discipline and then design curriculum to provide explicit support, training, and practice for students, in ways that are embedded in the domain.

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