MIDDLE SCHOOL STUDENTS' CONTEXTUALIZED GEOMETRIC SPATIAL UNDERSTANDINGS

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This study examined the spatial-scientific understandings of students from Kentucky (6th graders) and Nevada (8th graders). Quantitative data consisted of students completing a content survey as well as two spatial assessments at the conclusion of Earth-space instruction. Qualitative data involved student interviews concerning 2D Earth/Moon/Sun modeling. Findings showed Kentucky and Nevada students shared similar misconceptions regarding geometric motions, configurations, and spatial awareness to explain the physical phenomenon of lunar phases. Post data revealed significant differences in favor of Kentucky on lunar phases understanding related to the spatial domain of spatial projection (ability to visualize the Moon from multiple Earthly locations). Significant differences were also found in favor of Kentucky on the Geometric Spatial Assessment. No significant differences were found between students on mental rotation ability.

Keywords: Geometrical Spatial Thinking, STEM

Objectives

This research with middle level students from Kentucky (N=238) and Nevada (N=138) explored how well students from two geographically different locations understood lunar-related spatial-scientific content. The Next Generation Science Standards (NGSS Lead States, 2013) and Common Core State Standards-Math (National Governors Association, 2010) iterate the importance of student understandings related to spatial-scientific learning (i.e. scale, patterns, and geometric modeling). Previous research (Plummer et al., 2014, Black 2005) has linked increased spatial ability with an increased understanding of lunar phases. This study examined students' geometric spatial ability and how students developed and contextually applied this ability to their understandings concerning the phenomenon of lunar phases. The research question was: What geometric spatial factors might hinder or facilitate moon phase understanding? Factors could include students' understanding of scale of the Earth/Moon/Sun system, students' geographic perspective as they observe the moon, students' ability to recognize patterns, and students' aptitude to visualize in both 2D and 3D spaces.

Perspective: Spatial Reasoning and Scientific Performance

Students with high spatial reasoning tend to perform better on science assessments than students with low spatial ability; this has been found true on science assessments concerning chemistry, geoscience, physics, astronomy, calculus, and anatomy (Cole, Cohen, Wilhelm, & Lindell, 2018; Wilhelm, Toland, & Cole, 2017; Sorby, Casey, Veurink, & Dulaney, 2013). Wilhelm, Cole, Cohen, and Lindell (2018) argued that when spatial reasoning ability is advanced via an intervention or spatial experiences within a particular discipline, this spatial development should lead to improved understanding in other scientific disciplines. For example, in the Sorby et al. (2013) study, freshmen engineering students were separated into two groups (an intervention group and a comparison group) based on results of a mental rotation (MR) test. Students who scored low on the MR test were assigned to a spatial intervention course and those who scored above a passing cutoff grade were

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assigned to a comparison group. Sorby et al.'s findings showed the treatment group's scores increased after the intervention as shown on a post MR test, and even more interesting, treatment students displayed ***transfer*** effects as displayed in increased calculus performance.

Other studies have shown correlations between spatial reasoning and science performance as well as gender differences on spatial reasoning assessments. Guillot et al. (2006) researched the relationship between visuo-spatial representation, MR, and functional anatomy examination results. Guillot et al. (2006) measured visuo-spatial skills using the Group Embedded Figures Test (GEFT; Demick, 2014) which contains 18 complex figures. The test taker must identify a simple form by tracing the simple form within the complex form. MR was measured using the PSVT-Rot (Bodner & Guay, 1997). Guillot et al. found that males scored better than women in GEFT and the MR test; however, this "gender effect was limited to the interaction with MRT ability in the anatomy learning process. The correlations found between visual spatial and MR abilities and anatomy examination results underscore the advantage of students with high spatial abilities" (p. 504).

Spatial Thinking in an Astronomical Context

People interact with many aspects of astronomy on a daily basis, often without noticing them. They develop their own ways of knowing and explaining astronomical phenomena from their conscious and unconscious daily glances at the Moon and sky. In reality, these ideas are more complex than most people realize. In order to understand many aspects of astronomy, developed spatial thinking ability is required. The necessary spatial thinking skills vary by astronomy topic, but studies show that spatial reasoning ability contribute to understanding of astronomy (Wilhelm, et al., 2018). Spatial reasoning ability, as stated earlier, has been linked to performance in both mathematics and science (Black, 2005; Lord & Rupert, 1995; Wilhelm, 2009; Wilhelm, Jackson, Sullivan, & R. Wilhelm, 2013). In terms of lunar phases, spatial thinking ability in the domain of mental rotation is particularly important (Wilhelm et al., 2018). Historically, males have shown an advantage in spatial thinking, particularly in the area of mental rotation. "Countering this view is substantial evidence that environmental influences, in the form of experience in spatial activities from an early age and explicit training can eliminate sex differences on spatial tasks" (Linn & Petersen, 1985; Casey et al., 1999). Thus, it is important that spatially rich curricular experiences be examined to better understand how we can foster the development of factors that encourage students' geometric spatial understanding of scientific phenomena such as lunar phases.

Methods

Study Design

In order to determine what geometric spatial factors hinder or facilitate middle level students' lunar phases understanding, we utilized a mixed methods design. Students were purposefully selected from two different geographic locations so that we might be able to determine if sky viewing in a mountainous terrain would affect students' ability to accurately note Moon motion, Moon rise/set times, and visualization of relative positions of the Earth, Moon, and Sun as compared to Kentucky students in comparatively flat terrain. Quantitative data included the Lunar Phases Concept Inventory (LPCI; Lindell & Olsen, 2002), the Geometric Spatial Assessment (GSA; Wilhelm et al., 2007), and the Purdue Spatial Visualization Test-Rotations (PSVT-R; Bodner & Guay, 1997). The LPCI is a 20 question multiple choice test that assessed eight science domains as well as four spatial domains. The PSVT-Rot was a 20-item multiple choice survey that assessed the level of mental rotation reasoning. The GSA was a 16-item multiple choice test that assessed the same spatial domains addressed by the LPCI, but outside of a lunar context. The qualitative data included semi-structured interviews, where four students were chosen by each teacher for the interviews. Teachers were asked to select the girl and boy with the highest and lowest spatial ability in their classes.

Participants

Participants were from two states, Kentucky and Nevada. Subjects were drawn from one public school in Kentucky with three 6th-grade teachers and their students (N=238). The teaching experience of the Kentucky teachers ranged from 6 to 16 years. The Kentucky teachers' Earth-space curricular unit is outlined in Table 1. Three 8th-grade teachers in a public school in Nevada participated along with their students (N=138). Their teaching experience ranged from 3 to 14 years. Nevada teachers taught their Earth-space curricular unit as shown in Table 1. Grade years were chosen based on the grade lunar phases content was required to be taught in each state (6th grade for Kentucky and 8th grade for Nevada). Both Kentucky and Nevada teachers implemented their units in approximately 5 weeks and both curricula asked students to keep a Moon journal. The main difference in the two curricula was Nevada's emphasis on eclipses which was embedded within lessons on phases and scaling. Kentucky lessons incorporated ***Stellarium*** (software) to examine views and motions from both Northern and Southern hemispheres.

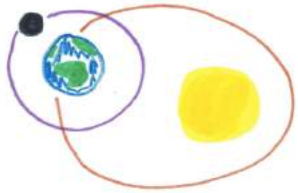
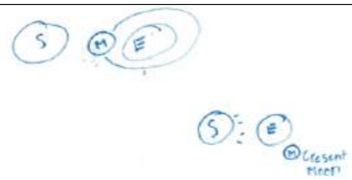
	Kentucky Curricular Unit	Nevada Curricular Unit
Lesson 1	***Can I see the Moon every night and why does it appear to change shape? -*** *Moon Journals* - Students keep daily Moon observation journals for 5 weeks.	***Ancient Civilization and the Moon***
		What's Up with the Moon? – Students record Moon observations for a month
Lesson 2	***How do I measure the distance between objects in the sky?***	
Stellarium	Students observe the apparent motion of the Moon over the course of a day and compare this motion for locations in the Northern and Southern hemispheres.	
Lesson 3	***How can I say where I am on the Earth?***	***Earth's Moon Vocabulary***
Lesson 4	***How can I locate things in the sky?***	***Determining Hours of Daylight***
Lesson 5	***Why do we have Seasons?***	***Origin of the Moon***
Lesson 6	***What can we learn by examining the Moon's surface?***	***The Sun-Earth-Moon system and Eclipses***
Lesson 7	***What affects a crater's size?***	***Eclipses***
Lesson 8	***The scaling Earth/Moon/Mars NASA Activity***	***Scaling the Sun-Earth-Moon system and Solar and Lunar Eclipses***
Lesson 9	***Moon Finale* - Lunar Phases Modeling**	

Table 1: Kentucky and Nevada Curricular Units

Results

Although both Kentucky (KY) and Nevada (NV) teachers asked their students to keep Moon journals for at least 4 weeks, a large portion of students in both locations failed to do so. As noted in Table 1, Nevada teachers placed a heavier emphasis on eclipses and taught this concept within lessons on phases and scaling. Qualitative interviews with high and low spatial ability NV and KY students showed similar ideas regarding geometric positioning of the Earth, Moon, and Sun for various lunar phases as well as how the Moon orbits the Earth. Table 2 illustrates representative samples of NV and KY high and low spatial ability students' geometric orientations and motions of the Earth/Moon/Sun system. Table 2 shows a High Nevada student modeling correctly the Moon's orbit around the Earth and the Earth's orbit around the Sun, and a High Kentucky student illustrating correctly the Earth/Moon/Sun geometry for New Moon and Waxing Crescent phase (although, neither representation is to scale). A Low Nevada student shows an incorrect understanding of the geometric configuration of a Waxing Crescent phase by demonstrating either an Earth blocking notion or an Earth's shadow misconception, and a Low Kentucky student revealed similar ideas to the Low Nevada student.

Table 2: Students' Geometric Spatial Orientations for Various Lunar Phases

High Nevada	High Kentucky
	
Low Nevada	Low Kentucky
	

Quantitative KY and NV survey results are shown in Figure 1 for the LPCI and the LPCI spatial domains: Geometric Spatial Visualization (GSV), Periodic Patterns (PP), Cardinal Directions (CD), and Spatial Projection (SP). Other results shown in Figure 1 are the PSVT-Rot test and the Geometric Spatial Assessment (GSA). Kentucky 6th grade students scored significantly higher on the SP domain items of the LPCI test and significantly higher on the GSA test than the 8th grade Nevada students. Test results showed KY and NV students had similar percentages of students holding classic misconceptions regarding cause of lunar phases explanations (object blocking (~10%), Sun's shadow (~25%), and Earth's shadow (~42%)).

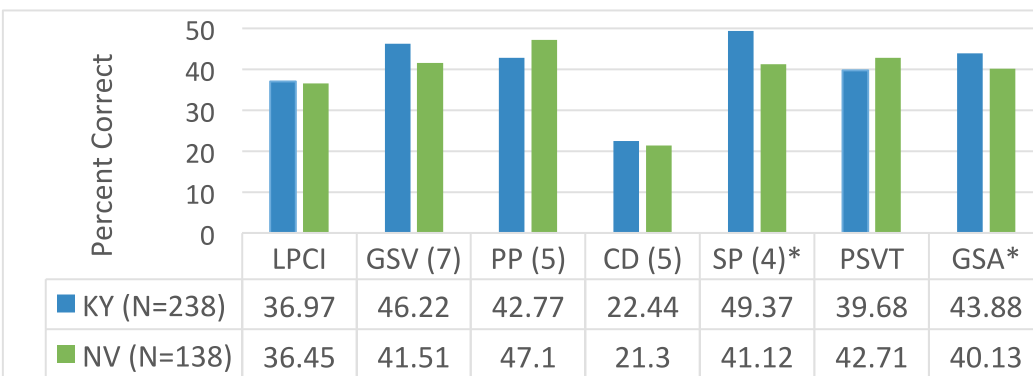


Figure 1: NV and KY students post scores on the LPCI by domain, PSVT, and GSA (*p < 0.05)

Discussion and Conclusion

Regardless of geographic region, students held similar misconceptions concerning the causes of the lunar phases (i.e. object blocking, Sun's shadow, and Earth's Shadow); however, KY students scored significantly higher on the SP domain that concerns visualizing how the Moon appears from various Earthly perspectives on same day. KY students also scored significantly higher on the Geometric Spatial Assessment. The GSA is not in a lunar context and assesses all four spatial domains (PP, GSV, CD, and SP). Possible explanations for the differences could be due to the heavy emphasis on eclipses in the NV curriculum which could have confused students since they were also trying to comprehend/visualize cause of lunar phases.

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