2017

USING STUDENT CHARACTERISTICS, STUDENT SPATIAL-CONTENT KNOWLEDGE, AND TEACHER SPATIAL-CONTENT KNOWLEDGE TO PREDICT STUDENT SPATIAL-CONTENT KNOWLEDGE OF LUNAR PHASES

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Digital Object Identifier: https://doi.org/10.13023/ETD.2017.322

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THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Education in the College of Education at the University of Kentucky

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2017

ABSTRACT OF THESIS

USING STUDENT CHARACTERISTICS, STUDENT SPATIAL-CONTENT KNOWLEDGE, AND TEACHER SPATIAL-CONTENT KNOWLEDGE TO PREDICT STUDENT SPATIAL-CONTENT KNOWLEDGE OF LUNAR PHASES

Student demographic characteristics of gender and race/ethnicity, students' spatial-content knowledge as measured by pre-instructional performance on the Lunar Phases Concept Inventory (LPCI) (Lindell & Olsen), and post-instructional performance on the Purdue Visualization of Rotations Test (PSVT-ROT) (Bodner & Guay, 1997), and teachers' spatial-content knowledge as measured by the two assessments were considered to predict students' overall understanding of lunar phases as measured by post-instructional results on the LPCI. A mixed modeling approach was used in a hierarchal manner to evaluate the student learning outcomes. Results showed that student gender was not a significant predictor of post-instructional student performance, but students who identified as "Other" for their race/ethnicity were shown to be a significant predictor. When considering pre-instructional spatial-content knowledge based on Wilhelm's four spatial-mathematical domains, Periodic patterns and Spatial Projection were found to be significant predictors, but the domains of Geometric & Spatial Visualization and Cardinal Directions were not found to be significant predictors. Students' post-instructional performance on the PSVT-ROT was found to be a significant predictor with student learning outcomes. Repeated Measures ANOVA tests showed that students' gain scores on the LPCI were significantly different for six of the seven teachers under consideration.

KEYWORDS: Moon Phases, Lunar Phases Concept Inventory, Spatial Ability, Purdue Spatial Visualization Rotation Test, Four Spatial & Mathematical Domains

Kyle Anderson Curry
August 1st, 2017

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August 1th, 2017

ACKNOWLEDGEMENTS

The follow Master's Thesis, while my individual work, is a result of the combined effort of several individuals who sacrificed a large quantity of their personal time to assist in my endeavor. My Thesis Chair, Dr. Jennifer Wilhelm of the University of Kentucky, has served as my mentor with regards to providing me the resources necessary to construct a well-crafted Master's Thesis that is grounded in existing research while simultaneously contributing to the literature. She has also provided me a flexible schedule to meet departmental deadlines so that I have had the necessary amount of time to provide quality revisions to the document. I would also like to personally thank Dr. Hongwie "Patrick" Yang of the University of Arizona for assisting me in constructing the many models that were used for the statistical analysis portion of the document; with my limited background knowledge with statistical analysis, Dr. Yang's guidance throughout this process has been invaluable in my efforts to succeed. Lastly, I would like to thank Dr. Merryn Cole for her advice and assistance throughout the Thesis writing process. Dr. Cole has specifically taught the critical skills necessary to create a quality literature review and accurate interpretation of statistical analysis results. This Thesis would not be possible without the explicitly assistance from each of these three individuals.

I need thank my soul mate, Kristen Taylor, for the patience that she has demonstrated during the many times in which I worked on this Thesis rather than spend my time with her. Even when I worked long hours composing this document, she displayed nothing but warmth, consideration, understanding, and unwavering support throughout the entire process. It would also be important to thank my father and mother for instilling the work ethic that is required to succeed in higher education. While both my father and mother never completed an undergraduate program, their appreciation for education and the emphasis on its importance has always been acknowledged.

I also need to thank the respondents of this study who shall remain anonymous for confidentiality purposes. Without their participation in the study, this document would not exist.

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Introduction

Throughout the human existence, universal themes that supersede time and space are also the same themes that establish a personal connection between each individual who inhabits the planet of Earth. These universal themes act as interrelated components of a network that allow for conversation, discussion, observation, and investigation regardless of the geographical, spatial, and temporal locations of the individuals under consideration. In a more specific case, consider the Earth's Moon. As the Moon orbits the Earth at a speed that exceeds 2,000 miles per hour, it is the same Moon that continuously governs the movement of Earth's oceans while simultaneously impacting the behavior of creatures that exist on the planet. The Moon has been referenced in religious and secular texts since the dawn of recorded human history, and continues to be prevalent in fictional and nonfictional texts in modern society. Just the simple act of observing the Moon during a clear night sky is a universal activity that all organisms on the Earth can relate. However, as with any universal theme, it is human nature to strive for a complete understanding of the Moon so that existing connections can be strengthened; all of this begins by asking relevant questions. Why does the Moon rise and set at different times each night? What causes the shapes of the illuminated portion of the Moon as it travels through the immediate, nearby cosmos? What influences the rate at which the Moon completes a full cycle of illumination and complete darkness? Does the Moon appear differently to different individuals based on their geographic location (Wilhelm, 2017)?

These questions can now also be answered by students who participate in project-based instructional units that give them authentic, natural experiences within a middle school setting; these units are simple to implement since the Moon can be viewed by all students regardless of where they live. At the completion of a project based unit pertaining to lunar phases, researchers, teachers, students, and other educational stakeholders may want to know what teacher and student characteristics are associated with the student success of understanding the phases of the Moon as it rotates on its internal axis and revolves around the Earth.

Participants of this study include 399 six grade students from five South-East-Central schools within a suburban region within the U.S.A. All of the students included in the study had one of seven different teachers. Classroom experience for the teachers ranged from 0 to 28 years of service. Each of the seven teachers who participated in this study identified as females who were White, Non-Hispanic. Each of the seven teachers implemented a project-based instructional, integrated mathematics-science curriculum known as Real Explorations in Astronomical Learning (REAL) (Wilhelm & Wilhelm, 2007) that emphasizes content pertaining to Earth and Space Science. The unit is intended to be implemented in the span of seven weeks, and has been designed to purposefully give students experiences with spatial geometric activities in which lunar phases can be explored through direct observations, journaling, illustrations, two-dimensional and three-dimensional modeling tasks, and classroom discussions. The specific goals of the unit are as outlined:

> (a) Foster learners' understanding of spatial scientific 'big ideas' through
> the development of innovative projects, benchmark lessons, and virtual learning communities; (b) Produce experiences for learners to "do mathematics" by challenging them to: i) analyze and represent situations graphically and

> geometrically, ii) observe patterns and functional relationships to make astronomical predictions, and iii) develop and employ spatial visualization skills to model and scale Solar System phenomena. (Wilhelm, Toland & Cole, 2017, p. 42)

Prior to the implementation of the unit, the seven teachers received professional development that allowed them to experience the REAL Curriculum (Wilhelm & Wilhelm, 2007) that integrated mathematics and science skills in an effort to address alternative conceptions of understanding the causes of lunar phases. This curriculum also allowed the teachers to develop and strengthen their spatial reasoning skills.

Both students and teachers completed twenty multiple choice items on the Lunar Phases Concept Inventory (LPCI) (Lindell & Olsen, 2002) in which questions were organized into the four spatial-mathematical domains (Wilhelm, 2009) of Periodic patterns (PP), Geometric Spatial Visualisation (GSV), Cardinal Directions (CD), and Spatial Projection (SP); these multiple choice questions were completed at various times throughout the academic school year in order to assess their understanding of lunar phases as a result of learning content and skills within the project based unit. Since the items on the LPCI contain lunar phases content questions that Wilhelm (2009) argues are connected to a student's spatial ability, the author of this text will refer to these items as measuring an individual's spatial-content knowledge of lunar phases. Students and teachers also completed twenty multiple choice items on the Purdue Visualization of Rotations Test (PSVT-ROT) (Bodner & Guay, 1997) at various times throughout an academic school year in order to assess their understanding of the mentally rotating irregular geometric objects. By considering student scores on both assessments before and after the unit was taught, teachers' scores on both assessments after the unit was taught, and demographic data associated with the students, this purpose of this study aims to investigate which student characteristics and students' and teachers' spatial-content knowledge are closely associated with the students' understanding of lunar phases after the implementation of a project based instructional unit pertaining to the phases of the Moon. Demographic characteristics of gender and race/ethnicity, characteristics of pre-instructional performance on the LPCI assessment, and post-instructional performance on the PSVT-ROT were considered for students. Teachers' spatial-content knowledge pertaining to their performance on the two assessments was also considered. Therefore, this study aims to specifically answer the following question: *How do student characteristics (gender and race/ethnicity), student spatial-content knowledge, and teacher spatial-content knowledge predict students' understanding of lunar phases at the conclusion of a project-based instructional unit?*

Literature Review

Historical Perspective And The Push For Lunar Education

As the state of America's educational system continues to evolve, an increasing number of curricula and science standards have been developed that emphasize the need for students to understand scientific phenomena in such a way that that they are able to use and develop models that are aligned with the currently accepted models that scientists use to explain the natural world. More than ever, individuals within the fields of education and science are emphasizing the need for students to understand the celestial motion of the

Moon as it travels along its path around the Earth. In the most recent example, The Next Generation Science Standards (NGSS, 2013), the latest set of standards adopted by eighteen states and the District of Columbia, and used by many states as a framework to help construct local standards, in an effort to prepare American students to be become contributing members of a global society within the twenty first century, states that students should be able to develop and use a model of a Sun-Earth-Moon system in order to describe the lunar cyclic patterns of the lunar phases (NGSS, 2013). However, the NGSS (2013) further emphasizes the need for students to understand content in connection with developing and using models in order to observe patterns by stating that students should be able: to use celestial objects such as the Sun, Moon, and the stars to describe patterns that can be predicted, use observations to describe patterns in the natural world, know and understand how the motion of the Earth and Moon in relation to the Sun are the cause for observable patterns, and develop and use models to describe, test, and predict phenomena. This explicit marriage between content and skills highlights the notion that students must grasp lunar phase content in the context of using their spatial ability.

While the Next Generation Science Standards are currently being used to guide science instruction, the push for students to learn about lunar cycles within the public educational system has also existed for several decades. While the following science standards are now defunct, according to the United States' National Science Education Standards (NSES), students between 5th grade and 8th grade should have developed:

> [A] clear notion about gravity, the shape of the earth, and the relative positions of the earth, sun, and moon' and realize that 'most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.' (National Research Council, 1996, pp. 159–160)

Even if the NSES (1996) are no longer in use, they can still be used to offer an historical perspective on curriculum evolution. Two decades ago, the commentary associated with the standards make it a point to state that over half of the students exposed to instruction pertaining to lunar phases will not be able to accurately explain the scientific concepts associated with the phases of the Moon. What makes this statement intriguing is the fact that the teams of individuals who write the standards readily admitted that a majority of students would most likely remain be ill-prepared to explain and understand the underlying scientific concepts of why lunar phases occur. This admittance of the gap between what students are supposed to know and what students actually end up knowing about lunar phases is one that is based is in agreement with studies that have tried to understand the issue in an effort to find a solution to circumvent the problem. This issue is one that is specifically addressed in this study.

Regardless of age, gender, race/ethnicity, and nationality, research exists that has shown that many students struggle with their understanding of lunar phases (Abell, Martini, & George, 2001; Baxter, 1989; Lightman & Sadler,1993; Plummer, 2015; Trundle, Atwood, & Christopher, 2002; Zeilik & Bisard, 2000). While one may suggest that many individuals on the planet have casually noticed that Moon appears to look different each night that they may look up into the sky, the referenced studies indicate that many individuals may hold different conceptions of the scientific phenomenon in a response to the need to make sense of the world around them (Hermann & Lewis, 2003); it has been found that individuals may latch onto underdeveloped, generalized conceptions of scientific phenomena even if the conceptions are challenged but heavily supported by new and existing research (Bar, Sneider, & Martimbeau 1997; Driver, Guesne, & Tiberghien 1985, Driver et al. 1994). The study of lunar cycles is one of those generalized scientific concepts in which students may hold on to refuted perspectives on lunar celestial motion even if scientific data exists that refutes the misconceptions associated with the phenomenon; Black (2004) stated within her study that understanding lunar phases was one of the most difficult concepts for university students to understand. For this reason, it is important that educational research try to determine the cause and remedy of why students struggle to revise their thinking even if facts exist to suggest information contrary to their own beliefs; this importance is further emphasized considering that lunar phases are required to be taught to students who are of middle school age (NGSS, 2013). While current literature acknowledges how students struggle to change their conceptions of lunar phases, some researchers have supplied more specificity in terms of the skills students lack that are necessary to reach a full understanding of the phenomenon.

Lunar Phase Content Knowledge And Students' Spatial Reasoning

In a study of students' understanding of the cyclic nature of Moon phases, Bayraktar (2009) implied that essential connections need to be made between several types of skills in order for desired student outcomes in their understanding of the Moon and its phases:

> First of all, students should know the rotating and revolving motions of the moon and the earth and their relative positions to the sun while they move. Second, they should know that the moon is lit by the sun and we can see only the illuminated portion of the moon by the sun. And that this illuminated portion differs in shape as the position of the earth and the moon system changes relative to the Sun. To make a sound understanding of the cause of lunar phases, students should synthesize all these information, and be able to construct a three dimensional image of this trio and their relative motions in their minds. (Bayraktar, 2009, p. 12)

With this acknowledgement of the connection between content and skills, Bayraktar (2009) explicitly raises a notion that helped form the conceptual framework used for this particular study. Bayraktar (2009) is not alone in the suggestion that a connection exists between students' content knowledge of lunar phases and the skills need to understand the rotations, revolutions, and orientation of celestial objects in order for the cyclic process of Moon phases to occur. Plummer (2014, 2015) has published articles pertaining to students' understanding of astronomical phenomena as it relates to students' spatial ability (in this text, spatial reasoning ability refers to a student's ability to mentally view, understand, and manipulate a given environment from different points of reference such as how a student could view a particular phase of the Moon from different locations on the Earth's surface). In a related study, it is suggested that students' spatial ability is flexible and malleable in that it can change with appropriate instructional and intervention strategies (Udomprasert et al., 2016). In a study conducted by Plummer, Bower, and Liben

(2015), 15 children between the ages of seven and nine were studied in how they make connections between frames of reference and perspective-taking skills with regards to the apparent motion of the Sun, Earth, and the Moon; students with a higher ability of spatial perspective-skills were able to make more explicit connections between frames of reference and celestial movement in several astronomical phenomena. Plummer argues that students' development of accurate models for astronomical phenomena and the celestial motion of objects can actually be defined by an increasing sophistication of spatial knowledge and reasoning (Plummer, 2014). These findings by Plummer were also used to form the conceptual framework of this study; even with a relatively small number of studies available, a students' understanding of lunar phases has been shown to be connected to a student's spatial reasoning ability (Ashmann, 2012; Cole, Wilhelm, & Yang, 2015; Coluccia & Louse, 2004; Jackson et al., 2015; Plummer, 2014; Plummer, 2015; Plummer, Bower, & Liben, 2016; Sherrod & Wilhelm, 2009; Udomprasert et al., 2016; Wilhelm, 2009; Wilhelm, 2014a; Wilhelm et al., 2013a; Wilhelm et al., 2013b; Wilhelm, Toland, & Cole, 2017). According to Wilhelm (2009), one cannot construct a complete understanding of lunar phases without a developed understanding of four mathematical and spatial concepts. According to Wilhelm (2009), the four mathematical and spatial concepts are summarized in Table 1.

Table 1. Wilhelm's Four Spatial-Mathematical Domains

Spatial-Mathematical Domain	Description
Geometric Spatial Visualization (GSV)	Visualizing the geometric features of a system from above/below/within the system's plane
Spatial Projection (SP)	Projecting to a different location and visualizing from that perspective
Cardinal Directions (CD)	Distinguishing directions (N, S, E, W) to document an object's vector position in space
Periodic Patterns (PP)	Recognizing occurrences at regular intervals of time and/or space

Note. (Wilhelm et al., 2013)

Wilhelm (2009) further explains that:

> Mental rotation is also involved [with Geometric Spatial Visualisation] since as one visualises the Moon/Earth/Sun three-body system in space above/below/within, one must also manipulate and consider the motion of the system itself. (Wilhelm, 2009, p. 2108).

Based on Wilhelm's categorization of the four mathematical domains associated with a student's spatial ability, it is important that students' and teachers' conceptions of lunar phases be analyzed in the context of the conceptual framework that has been outlined by Wilhelm (2009). It is through Wilhelm's (2009) lens that this study is based. With the need to make connections between scientific content knowledge, mathematical reasoning, and geometric understanding of objects that can change their orientation, multiple educational studies have been conducted to identify the misconceptions that students and teachers have regarding lunar cycles. These misconceptions must be acknowledged in order to make connections to students' attempts to relate these connections to their spatial ability.

Student Misconceptions Of Lunar Phases

Within the U.S.A, it is typical that students of the traditional educational system and those who adopt more modern approaches to providing science instruction begin their in-depth study of lunar phases in years associated with middle school; further conceptions of the celestial motion of the Moon are developed and solidified in the years prior to their years engaged with higher education. Regardless of when students study lunar phases, common themes have been found in students' understanding of lunar phases. Research pertaining to middle school students' and high school students' understanding and misunderstanding of lunar phases can be classified into four separate categories as identified by Wilhelm (2014a): Cloud Coverage or the Blocking Notion, Earth's shadow on the Moon, the Sun's Shadow on the Moon, and the scientifically accurate portion of the Moon's illuminated side visible from an Earthly perspective (Baxter, 1989; Hermann & Lewis, 2003).

One way in which students rationalize the phases of the Moon is due to a belief of the Earth's clouds blocking different amounts of light that can be observed as coming from the Moon. In a study conducted by Stahley, Krockover, and Shepardson (1999), students were reported to have indicated that the shape of the Moon within the sky was a direct result of the area of the Moon not covered by clouds within the sky; clouds within the Earth's atmosphere were thick, dense, and large enough to effectively prevent any light coming from the Moon to pass through the clouds in order to reach an observer's eye.

Even if students dismiss the notion that the Earth's atmosphere creates the phases of the Moon, one of the largest misconceptions associated with lunar phases is the notion that the mechanisms responsible for lunar eclipses can be used to explain lunar phases. When considering students in middle school and high school, the most common misconception pertaining to lunar phases is that the Earth casts a shadow on the surface of the Moon as a result of Earth's position and Moon's position relative to the Sun (Wilhelm, 2014a). In Hermann and Lewis' 2003 study regarding lunar phases, over 60.7% of students assessed indicated that the Earth's shadow falling on the lunar surface is what caused the observed lunar phases; even after instruction took place to help address student misconceptions, only 52.9% of students were able to correctly indicate that lunar phases are a result of the changes within the visible portion of the illuminated side of the Moon as a result of its position relative to the Sun. In the same study, even after instruction, 52.9% of students tested were able to correctly identify the correct orientation of a Sun-Earth-Moon system needed for an observer on the Earth to see half of an illuminated Moon. In the same study, more than 40.2% of students still indicated that the Earth's shadow being cast on the Moon's surface was the cause for the lunar phases. In the Bisard et al. (1994) study of American students, it was found that only 40% of students studied between middle school and the university level understood that the Moon's phases were due to the reflected sunlight from the Moon. This common misconception is not limited to students who exclusively study in the U.S.A.; an Israeli study, Trumper (2001), found similar findings to Hermann and Lewis' findings (2003) while an Australian study of middle school students, Danaia and McKinnon (2007), found that the Earth-shadow explanation of lunar phases accounted for 27.7% of seventh graders' understanding of the phenomenon and 29.7% of eighth graders understanding of the phenomenon before instruction was implemented. Barnett and Morran's study (2002) of fifth grade students' understanding of lunar phases and eclipses found that most of the fifth grade students explained lunar phases in the same way that lunar eclipses and solar eclipses take place; the "shadow" explanation is further reinforced by Schoon's study (1992) that found that the eclipse explanation of lunar phases was given by 48% of the student participants. These findings potentially show deficits in students' spatial ability to separate the mechanisms responsible for eclipses and those responsible for the observed phases of the Moon; a deficit that has now been shown to exist with young students and students who are enrolled in higher education institutions.

While the eclipse-explanation or "shadow" misunderstanding may be one of the most common misconceptions that students have regarding lunar phases, various other misconceptions have been identified with young students. In a qualitative study intended to explore young children's (five and six years of age) thoughts regarding natural phenomena pertaining to the Moon's different phases, Wilhelm (2014a) showed two students believed that the visible portions of the Moon are a result of light from the Sun, situated behind the Moon, filtered through the Moon; this misconception is at odds with the correct explanation of Moon illumination being a direct result of sunlight reflecting from the Moon's surface and reaching an observer's eyes. Within the context of the interview, a third student provided an alternative explanation that the Moon had different phases due to the belief that "night" became darker and lighter corresponding to a visible Moon and a Moon that cannot be observed. Another student within the study explained that he was unsure of why the Moon exhibited different phases. A fifth student went as far as to say that the Moon was alive since it could be observed in the night sky. As another alternative explanation of why lunar phases exist, Stahley, Krockover, and Shepardson's study (1999) showed that third grade students reached a conclusion in which an individual on the Earth can observe different Moon phases at different times as a result of changing the individual's location on the Earth. While it would seem that these findings are not immediately applicable to middle school students' understanding of lunar phases, it has already been shown that a student's initial understanding of scientific phenomena can remain and incorrectly evolve even if information exists that can contradict the student's misconceptions.

Even with the student misconceptions that have been identified by the referenced studies, there is still a larger than desired gap in the research to fully understand students' thoughts and conceptions associated with the spatial principles of the phases of the Moon; conceptions that may exist and persist as a result of students' lack of spatial ability (Ashmann, 2012; Cole, Wilhelm, & Yang, 2015; Coluccia & Louse, 2004; Jackson et al., 2015; Plummer, 2014; Plummer, 2015; Plummer, Bower, &Liben, 2016; Sherrod & Wilhelm, 2009; Udomprasert et al., 2016; Wilhelm, 2009; Wilhelm, 2014a; Wilhelm et al., 2013a; Wilhelm et al., 2013b; Wilhelm, Toland, & Cole, 2017).

Since students of all ages have been shown to exhibit misconceptions for the causes of lunar phases, it would possibly prove to be beneficial for the study to specifically examine how a student's demographic is associated with a students' spatial-content knowledge of lunar phases.

Student Gender Differences On Student Performance

Since literature is limited regarding students' conceptual and spatial understanding of lunar phases, it must be stated that, at the moment, it is difficult to fully categorize how student demographics can influence a students' ability to make the essential connections to form an acceptable model that can explain the phases of the Moon. At the time in which this text has been published, the literature is growing with regards to the number of studies associated with student gender differences with regards to their spatial and conceptual understanding of lunar phases. Differences in gender pertaining to spatial ability have been well documented, even without the context of lunar phases, within the twenty first century (Coluccia & Louse, 2004; Halpern, 2007; Levine et al., 2005); it is bridging the gap between a student's spatial ability and content knowledge that has driven this study.

With regards to a student's spatial ability, boys have been found to exhibit higher performance on a variety of assessments when compared to girls (Halpern et al., 2007; Jackson et al., 2015; Linn & Petersen, 1985; Voyer, 1996; Voyer et al., 1995; Wilhelm, 2009, Wilhelm, Toland & Cole, 2017). The gender performance difference pertaining to students' spatial ability has even been observed with students as young as first graders (Tzuriel & Egozi, 2010). In a study conducted by Ganley, Vasilyeva, and Dulaney (2014), a sample of 73,245 eight-grade students of a given state population found that gender performance differences existed on state assessment items that were related to the concept of mental rotation. The authors within the same study state that, in general, "the largest male advantage is found on mental rotation tasks, which require mentally generating and manipulating images (Linn & Petersen, 1985; Vandenberg & Kuse, 1978)" (Ganley, Vasilyeva, & Dulaney, 2014, p. 1421).

Based on the previous studies, it is then argued that if boys have been shown to outscore girls on pre-instructional and post-instructional assessments that measure spatial ability, it stands to reason that boys will more than likely outscore girls with regards to science concepts that rely on these skills; such as with lunar phases content that Wilhelm (2009) argues to be connected with spatial ability. Since a complete understanding of lunar phases has been connected with an understanding of the revolutions and rotations of the Earth and the Moon as they travel around the Sun, it stands to reason that students would need to develop a strong understanding of how geometric shape orientation changes as a result of rotation and revolution tasks of mental and physical means. With this line of reasoning, it is then pertinent to show that boys have outperform girls on a variety of rotational tasks over the last several decades (Linn & Petersen, 1985; Lippa, Collaer, & Peters, 2010). The existing literature has further shown that the difference between boys' and girls' spatial ability is more prevalent when considering mental rotations and spatial perceptions of objects (Voyer, Voyer, & Bryden, 1995). According to another study (Halpern et al., 2007), boys score higher than girls on standardized assessments in science and mathematics, which has been argued to correlate with boys' ability to spatially reason (Wilhelm, 2009).

While the study of students' spatial ability in the context of lunar phases may be in its infancy in educational research, several studies currently exist to highlight the gender differences between students' understanding of the lunar cycles. Examining the gender differences in 123 middle-school level students' (53 boys and 70 girls) understanding of lunar phases was the subject of a research study conducted by Wilhelm (2009). In the study, lessons pertaining to the lunar phases were constructed based on the REAL Curriculum; assessing student understanding of lunar phases was based on the student pre-scores and post-test scores from the LPCI assessment and the Geometric Spatial Assessment (GSA) (Wilhelm et al., 2007), a 16 item multiple choice instrument used to "ascertain the development of the students' spatial understandings from pre to post project implementation" (Wilhelm, 2009, p. 2111). As a result of pre-assessment and post-assessment comparisons of Wilhelm's four spatial-mathematical domains, boys and girls made a similar percentage of gains within Periodic Patterns and Spatial Projection. However, boys significantly scored higher than girls when considering the Geometric Spatial Visualization domain, which is found to be consistent with the similar studies by Linn and Petersen (1985) along with Lippa, Collaer, and Peters (2010) that measured students' general spatial ability. These findings are similar to what and earlier study by Bishop (1996) found; hands on learning strategies designed to improve students' spatial abilities improved all students' understanding of lunar phases; improving all students' understanding of lunar phases is helpful in providing girls with more opportunities to increase understanding.

As a result of her study, Wilhelm (2009) suggested that the instructional intervention gave girls the opportunity to develop their spatial reasoning skills when their boy peers may have already done so prior to instruction. Analysis of students' GSA scores showed a significant increase in the average overall GSA score from pre-instruction to post-instruction, and that 15.1% of the gain could be attributed to the implementation of the REAL Curriculum. When considering gender characteristics, boys gained 5.8% in average overall GSA score from pre-instruction to post-instruction while girls gained 7.5%; no significant difference was found between gender groups on overall post-GSA scores, and boys and girls made similar gains within the spatial-mathematical domains of Geometric Spatial Visualization and Spatial Projection. However, boys made a 7.9% gain and girls made a 10.5% gain on Periodic Patterns. Furthermore, "girls' gain score nearly doubled that of the boys' score for the mathematics domain of *cardinal direction*. Boys finished with an insignificant gain of 7%, and the girls achieved a significant gain score of 12% on the Cardinal Direction domain" (Wilhelm, 2009, p. 2118). At the conclusion of her study, Wilhelm (2009) suggested that the implementation of the REAL Curriculum helped closed the gender gap from pre-instruction to post-instruction even though girls scored lower than boys on every domain that was measured before instruction was implemented. The study also showed that girls made gains that brought each of their spatial-mathematical domains up to or exceeding their boy peers that could be attributed to providing girls with instructional strategies that better meet their learning needs.

Wilhelm, Toland, and Cole (2017) conducted a study in which "differences were examined between groups of sixth grade students' spatial-scientific development with regards implementation of an Earth/Space unit. Treatment teachers employed a spatially-integrated Earth/Space curriculum [REAL], while control teachers implemented their Business as Usual (BAU) Earth/Space units" (Wilhelm, Toland, & Cole, 2017, p. 40). The study was conducted to determine if gender and/or race/ethnicity is associated with students' performance on tasks related to lunar phases. When viewing overall gain scores on the LPCI from pre-instruction to post-instruction, analysis of descriptive statistics showed that white girls who received treatment instruction demonstrated instructional gains of 3.15% as compared to white boys who received treatment instruction who only gained 2.78% points. In the same study, girls of color who received treatment instruction demonstrated gains of 2.47% points while boys of color who received treatment instruction demonstrated gains of 2.75%. It is important to highlight this information when one considers similar comparisons that were made for students who received the BAU instruction. White girls who received BAU instruction demonstrated instructional gains of 1.18% as compared to white boys who received BAU instruction who gained 3.07% points. Girls of color who received BAU instruction demonstrated gains of -0.12% points while boys of color who received BAU instruction demonstrated gains of 2.16%. These same trends with gain scores can also be found when examining the spatial-mathematics domains of Period Patterns, Geometric Spatial Visualization, Spatial Projection, and on the PSVT-ROT assessment. It is important to note, however, that boys tended to have higher pretest scores on the overall LPCI than girls adjusting for teacher characteristics of gender, ethnicity, years teaching, and highest degree earned. When considering the Periodic Patterns spatial-mathematical domain:

> [B]oys scored higher than girls in the [Business as Usual] group…but this gender difference was not maintained in the Treatment group. Or, it could be understood to meaning that girls in the Treatment group scored higher than girls in the [Business as Usual] group while boys in the Treatment group scored lower than boys in the [Business as Usual] group. (Wilhelm, Toland, & Cole, 2017, p. 46)

Boys, regardless of instruction, were also found to outscore girls on the pre-test items associated with Geometric Spatial Visualization. The domain of Spatial Projection was found not to have any statistical pre-score difference with regards to gender within both instructional groups, but boys, in general, tended to outscore girls on post-test items associated with Geometric Spatial Visualization. However, based on the comparison of gain scores between students receiving treatment instruction and BAU instruction, an argument can be made that project based instruction and the implementation of the REAL Curriculum better served girls in terms of increasing their understanding of lunar phases; also in agreement with the conclusions reached by the authors of the study.

As of now, to the best knowledge of the author, only a small number of studies have addressed the differences of students' spatial-content knowledge before and after an integrated mathematics and science curricular unit has been implemented with regards to gender. The lack of research served as a basis to examine the associations that exist between students' understanding of lunar phases with regards to their gender.

Student Race/Ethnicity On Student Performance

At the moment of the publication of this text, existing literature pertaining to student spatial-content knowledge of lunar phases with regards to race/ethnicity is limited, and the limitations are far greater than those that exist for identifying the possible gender differences in students' understanding of lunar phases. However, researchers Campbell

(1989) and Manning (1998) argue that future researchers should consider racial differences when conducting studies pertaining to gender and academic performance on various assessments. When analyzing the results of the study conducted by the National Assessment of Educational Progress for the United States (1996), a study conducted by McGraw, Lubienski, and Strutchens (2006) found that boy, White, Non-Hispanic students had higher end score distributions and were the most consistent scores within the study. More literature is available in which researchers have conducted studies regarding differences in mathematical performance between Black and White, Non-Hispanic students have been observed (Lee, 2004; Lee & Wong, 2004; Lubienski, 2002; Reyes & Stanic, 1988). Differences in mathematical performance between White, Non-Hispanic and Hispanic students have also been highlighted in Lubienski's study (2002); White, Non-Hispanic students have shown to perform at a higher level than Hispanic students with regards to mathematical ability.

There are a small number of researchers who have sought to fill in the gaps that exist within the literature with regards to students' spatial-content knowledge pertaining to lunar phases. In the study by Wilhelm, Toland, and Cole (2017), the authors state that "LPCI pretest scores, gender, and race/ethnicity were each statistically significant predictors of LPCI posttest scores regardless of treatment condition" (Wilhelm, Toland, & Cole, 2017, p. 46). When referring back to the descriptive statistics reported by the authors, overall LPCI gain scores show that boys of color who received treatment instruction demonstrated gains of 2.75%, which is only 0.03% points lower than White, Non-Hispanic boys who received treatment instruction. Compare these results within the BAU group in which White, Non-Hispanic boys demonstrated gains of 3.07% while boys of color within the BAU group only made gains of 2.16%. These differences are further highlighted when one considers gains made by girls. Overall LPCI gain scores show that girls of color who received BAU instruction demonstrated gains of -0.12% (a decrease in post-score from pre-score) while White, Non-Hispanic girls who received BAU instruction demonstrated gains of 1.18%; BAU instruction was shown to have a negative effect on girls of color. With regards to boys within the BAU group, White, Non-Hispanic Boys scored 0.89% higher than boys of color who made gains of 2.16%. Similar findings were also found within the spatial-mathematical domains of Periodic Patterns, Geometric and Spatial Visualization, and Spatial Projection; girls of color actually showed negative gains on items pertaining to Periodic Patterns when receiving BAU instruction. Overall results on the LPCI assessment showed that White, Non-Hispanic students outperformed students of color whenever BAU instructional approaches were implemented in the classroom. Wilhelm et al., (2013a) also found in a previous study that White, Non-Hispanic students outperformed students of color with regards to assessment items associated with the four spatial-mathematical domains on the LPCI assessment, which is in agreement with a second study by Wilhelm et al. (2013b). It is important to point out that in a study by Jackson et al. (2015), students of color within a control group and experimental group of tested students achieved higher overall gain scores on the PSVT-ROT, which does serve as a study that suggests that the race/ethnicity gap can be narrowed as a result of targeted, meaningful instruction. More importantly, using the results from Wilhelm, Toland, and Cole's study (2017), the argument can be made that students of color can more greatly benefit from receiving project based instruction when compared traditional forms of instruction; the REAL Curriculum was better able to serve the needs of students of color than traditional forms of instruction when considering how much a student was able to increase her/his knowledge of lunar phases.

However, little research has been found by the author to specifically address if race/ethnicity is associated with student performance success in the context of lunar phases and the four spatial-mathematical domains. However, Wilhelm, Toland, and Cole (2017) state that they it may be beneficial for future studies to examine “how well spatially-oriented, STEM-integrated Earth/Space curricula can advance students’ learning, especially for girls and students of color” (Wilhelm, Toland, & Cole, 2017, p. 48). The lack of research served as a basis to examine the associations that exist between students’ understanding of lunar phases with regards to their race/ethnicity.

Teacher Misconceptions Of Lunar Phases

Since students may rely on teachers’ pedagogical content knowledge pertaining to content that is to be learned, it is critical that teachers in the field and pre-service teachers develop a sophisticated and scientifically accurate understanding of the physical world around them. It has been shown that the degree of knowledge that teachers have regarding the science disciplines that they teach can have a major effect on the pedagogical approaches and instructional strategies that teachers use to educate their students (Schulman, 1986; Osborne & Simon, 1996). In a recent study conducted by Wilhelm et al. (2017), analysis of LPCI pre-score found that teachers held alternative conceptions regarding lunar phases while only one third of the teachers who participated in the study were able to accurately explain the phases of the Moon. Therefore, decades of research exist that highlights teachers’ struggle with understanding the phases of the Moon.

While students have been shown to construct improper understandings of lunar phases, educators have been found to do the same. It has been shown that if students develop misconceptions regarding lunar phases, these misconceptions can exist even when the students become adults (Parker & Heywood, 2007). This can be attributed to findings by Schneps and Sadler (1989) that suggest that misconceptions pertaining to the Earth and Astronomy can be difficult to revise even after instruction has been implemented and a large time passage occurs; revising student thinking can be difficult whenever a students’ childhood observations are at odds with the scientific principles needed to accurately explain a given phenomenon. As some of these adults transition into careers that involve educating children about scientific phenomena, pre-service teachers and established classroom teachers may continue to hold these misconceptions unless they are also given opportunities to revise their own understanding.

An explanation of lunar phases as a result of an eclipse mechanism is not exclusive to students who they teach. In alignment with students’ misconceptions regarding lunar phases, the eclipse explanation was also identified by Wilhelm et al. (2017) with 41.70% of teachers who ranged in teaching experience from 0 years to 28 years. In a study of 154 Turkish, third year primary student teachers, 46% of the student teachers were categorized as having misconceptions regarding why the Moon is seen as different shapes when looking at the night sky at different times (Bayraktar, 2009). In agreement with misconceptions that students attribute to the causes of lunar phases, many of the 46% of teachers with misconceptions within the study explained that lunar phases were a result of the Earth’s shadow on the Moon; other teachers described lunar phases as a function of the Earth’s rotation or the varying distance between the Earth and the Moon. In a related finding, Wilhelm, Toland, & Cole (2017) identified a cloud coverage or blocking explanation for lunar phases; 12.5% of the teachers who participated in the study explained lunar phases by stating that the phases of the Moon may result from a cloud, a celestial object, or a black space that is able to block portions of an illuminated moon. In the same study, the authors also identified that teachers struggled with size and scale of celestial objects associated with an astronomical context.

While much research exists pertaining to experienced teachers and their struggles with understanding lunar phases, several studies have also been conducted regarding pre-service teachers. In a study by Suzuki (2003), pre-service teachers' conversations within university science classes were documented, and it was found that an eclipse explanation of lunar phases was present in many of the participants' dialogues. Trumper (2001) conducted a study in Israel regarding educators' understanding of lunar phases; Trumper found that 27% of pre-service elementary school teachers, 16% of pre-service high school teachers, and 25% of teachers of a major other than science believed that the cause of the lunar phases is a result of the Earth's shadow falling on the Moon. Referring back to Trundle, Atwood, and Christopher's study (2002), 23% of the 78 pre-service teachers sampled explained lunar phases in the same manner in which eclipses are explained; 7.6% of the teachers within the study explained lunar phases as a result of the Earth's rotation on its axis. Schoon's study (1995) found that only 18% of 122 elementary pre-service teachers displayed an accurate understanding of the scientific concepts associated with lunar phases. Callison and Wright (1993) found in their study of 76 pre-service elementary school teachers that only 6% of the participants held an accurate understanding of lunar phases before the teachers engaged in classroom instruction with their students. Arslan et al. (2016) went as far as to state that "…there had been an expectation that science and physics preservice teachers had more scientific knowledge about astronomy topics than the rest, because of the relatedness of their departments. This, in fact, was not the case" (Arslan et al., 2016, p. 107).

With a large quantity of studies that have identified areas in which teachers and pre-service teachers struggle with their understanding of lunar phases, it is important to refer to the existing literature that address how students, teachers, and pre-service teachers attempt to revise their alternative conceptions.

Issues Of Revising Conceptions Pertaining To Lunar Phases

It has been suggested that one reason why students, and therefore adults who were once students, stubbornly hold on to misconceptions pertaining to lunar phases is due in part to the notion that most astronomical concepts are three-dimensional in nature; the objects within an Sun-Earth-Moon system move in various planes as they continue their trajectory within their harmonious cycles. However, textbooks and the increasing use of internet resources depict these concepts in a two dimensional form (Ashmann, 2012). Ashmann also explains that it is common that a single two dimensional depiction of a three dimensional astronomical concept will depict two different frames of reference that are seemingly contrary from a student perspective; one frame of reference in which the Sun, Moon, and the Earth are viewed from an observer in outer space and a second frame of reference of the Sun-Earth-Moon system being viewed as if the observer is situated on the

Earth's surface. Furthermore, Ashmann makes the case that students need more experience switching between different frames of reference in order to analyze the celestial motions of the objects within a Sun-Earth-Moon system; this is in agreement with Wilhelm's study (2009) that provides clarity on the spatial abilities that students may need in order to become successful in understanding the phases of the Moon. In a study by Plummer, Bower, and Liben (2015), the authors found that children with lower perspective-taking skills, in relation to their peers, may need more intervention and support in making the connection between frames of reference and astronomical phenomena. In relation to students' spatial abilities, Fanetti (2001) attributes misunderstandings of lunar phases to the possibility that individuals struggling with lunar concepts have difficulty visualizing the scope and scale associated with the sizes and distances between the celestial bodies of the Sun-Earth-Moon system. Fanetti's findings are in agreements with those of Wilhelm (2015) and Callison and Wright (1993) in which students may require a more sophisticated spatial reasoning ability.

Other researchers have provided more possible answers as to why it has become so difficult to revise students' misconceptions pertaining to lunar phases. In one of the most troubling studies, in a review of 80 children's books pertaining to the Moon and its phases, Trundle, Troland, and Pritchard (2008) found that many children's textbooks misrepresent the mechanisms of lunar motion, and contain diagrams and depictions that can further reinforce students' misconceptions of lunar behavior. Suzuki's study (2003) the attributes to students' and teachers' ecliptic misunderstanding of lunar phases is a result of large amount of attention that the Moon receives as a result of mainstream discussions regarding eclipses whenever they occur.

With research showing why students and teachers may resist in revising their misconceptions of concepts, there is hope that these revisions can effectively take place. In Hermann and Lewis' study (2003) of students between the ages of 9-16, a three step teaching strategy was implemented to address the misconceptions that have been highlighted; identify the misconception, overturn the misconception, and replace it with a more accurate, scientifically accepted conception of the phenomenon (Posner et al., 1982). With the established framework, Hermann and Lewis constructed a series of lessons to determine its effectiveness in revising students' thinking regarding lunar phases. By implementing a five question pre-assessment, the authors of the study were able to identify the misconceptions so that instructional lessons could be tailored to the needs of the students under consideration. After delivering inquiry-based instruction to the student population, students were re-tested to gauge how much students' understanding of lunar phases changed. With regards to the three multiple choice questions contained within the assessment, the proportion of correct answers on the post-test approximately doubled when compared to the scores on the pre-assessment; in each of the questions under consideration, however, approximately one half of the students still held onto misconceptions pertaining to lunar phases. While growth was found to be significant, the growth still concurs with the original discussion pertaining to how difficult it is to revise students' thinking of concepts. Hermann and Lewis' findings (2003) are in agreement with Stahley, Krockover, and Shepardson (1999) in that students may continue to latch onto their misconceptions of lunar phases even after instruction has been delivered to the students.

Teachers have also been found to struggle with revising their misconceptions regarding lunar phases. Trundle, Atwood, and Christopher (2002) performed a qualitative study with 78 pre-service elementary teachers before and after they implemented a project based instruction lunar phases unit. The data collected from the study involved classroom observations, artifact analysis, and structured interviews that took place before the unit was taught and after the unit was taught. The results of their study showed that before instruction took place, only 10% of pre-service teachers held correct scientific conceptions of lunar phases. Once the unit was taught, 93.7% of pre-service teachers held correct scientific conceptions of lunar phases.

In the Wilhelm, Toland & Cole (2017) study:

> The most difficult items for teachers were those concerning cardinal direction with an average percent correct of 36.70%. Analysis of the LPCI test items revealed that not only did teachers not understand the cause of lunar phases, but they also had limited understanding of the apparent daily lunar motion (as a result of the Earth's spinning on its axis) where the Moon rises in the East and sets in the West and that each phase has different rise and set times. (Wilhelm, Toland & Cole, 2017, p. 11)

These identified difficulties within the four spatial-mathematical domains may later provide insight into how revision of teachers' alternative conceptions to lunar phases can be effectively implemented.

The issues associated with revising students' understanding of lunar cycles as it is potentially associated with their spatial ability is one of great concern that can be furthered studied when taking into consideration the possible student spatial ability characteristics and demographics along with teachers' spatial-content knowledge associated with student performance on spatial ability tasks that are set within a lunar phase context; this need is the primary driver of the research contained within this text.

Purpose Of The Study

The existing research that has been cited suggests that students' spatial ability may be necessary in their success in developing and using accurate scientific models of the cyclic nature of the phases of the Moon. The research also suggests that student demographics such as their gender and race/ethnicity could impact how students develop and use their spatial ability in an effort to grasp the concepts necessary to understand the lunar phases. Existing research has also been referenced that students' and teachers' spatial ability and content knowledge may also be associated with overall student success in terms of understanding the phenomenon. With the acknowledgement of the gaps in literature with regards to the identification of student misconceptions of lunar phases, differences in performance of students' understanding of lunar phases based on demographic data such as gender and race/ethnicity, and the association of Wilhelm's categorized spatial-mathematical domains of student spatial ability, this study aims to add more knowledge within this specific area of educational research by answering the following question: *How do student characteristics (gender and race/ethnicity), student spatial-content knowledge, and teacher spatial-content knowledge predict students' understanding of lunar phases at the conclusion of a project-based instructional unit?* As a result of this quantitative study, researchers will be able to view data regarding how the student characteristics and teachers' spatial-content knowledge identified within the text are associated with students' understanding of the phases of the Moon.

Methods

Participants

Participants of the study include six grade students from five South-East-Central schools within a suburban region within the USA. All of the students included in the study had one of seven different teachers who ranged from 0 years of teaching experience to 28 years of teaching experience. The demographics of the students who participated in the study can be found in Table 2.

Table 2. Demographic Student Breakdown of Race/Ethnicity and Gender

Race	Boys	Girls	Total
White, Non-Hispanic	98	147	245
African American	10	20	30
African (Not American)	1	3	4
Hispanic American	9	13	22
Asian American	5	8	13
Asian (Not American)	6	8	14
Native American	3	3	6
Other	14	21	35
Declined to Answer	16	10	26
Missing	2	2	4
Total	164	235	399

Each of the seven teachers who participated in this study identified as females who were White, Non-Hispanic. Each of the seven teachers implemented a project-based instructional curriculum known as Real Explorations in Astronomical Learning (REAL) that emphasized content pertaining to Earth and Space Science. More specifically, a portion of the unit addressed the concepts and skills necessary for students to reach a complete understanding of the principles associated with the phases of the Moon. The integrated mathematics and science unit was intended to be implemented in the span of seven weeks, and had been designed to purposefully give students experiences with spatial geometric activities in which lunar phases could be explored through direct observations, journaling, illustrations, two-dimensional and three-dimensional modeling tasks, and classroom discussions.

The total number of students who participated in the study, N, was 399; 66 students in Teacher 1's class, 70 students in Teacher 2's class, 74 students in Teacher 3's class, 22 students in Teacher 4's class, 66 students in Teacher 5's class, 72 students in Teacher 6's class, and 29 students in Teacher 7's class.

Assessment Measures

Two sources of data were used within this study. One source of data used within this study was collected from student and teacher responses from the LPCI assessment. The questions contained within the assessment were categorized into four spatial-mathematical domains; the LPCI assessment was used to assess student performance pertaining to their understanding of spatial-content knowledge regarding the phases of the Moon as a result of the position of the celestial objects within a Sun-Earth-Moon system. The second source of data used within this study was collected from student and teacher responses from the PSVT-ROT.

1. Lunar Phases Concept Inventory - LPCI Assessment

This assessment, developed by Lindell and Olsen (2002), is a 20 item multiple choice test that assessed lunar phases content knowledge in which the items were classified into four spatial-mathematical domains by Wilhelm (2009). The LPCI assessment is also intended to assess students' mental models of lunar phases as a result of the movement of the celestial objects within a Sun-Moon-Earth system. This assessment was given to each of the seven teachers' respective students prior to the teachers' implementation of the unit and after the unit had been taught. This assessment was also given to each of the seven teachers before receiving professional development pertaining to the implementation of the unit, after receiving professional development but prior to teaching the unit to the students, and then after the unit was taught to the students. This assessment was one of two used within this study to gain quantitative data with regards to the research question.

2. The Purdue Visualization Of Rotations Test - PSVT-ROT

This assessment, developed by Bodner and Guay (1997), is a 20 question abridged version of a 30 question element of the PSVT-ROT. In this assessment, students are given irregular geometric shapes that they must mentally rotate in order to determine how the item can be viewed from a different perspective. The students are given five multiple choice items that they must choose from by selecting a single choice that represents the correct mentally rotated figure. The assessment contains questions in which the irregular geometric shapes are rotated around one or more axes. This assessment was given to each of the seven teacher's respective students prior to the teachers' implementation of the science unit and after the science unit had been taught. This assessment was also given to each of the seven teachers before receiving professional development, after receiving professional development but prior to teaching the unit to the students, and then after the unit was taught to the students. This assessment is one of two used within this study to gain quantitative data with regards to the research question.

Statistical Analysis

In this study, the effects of various potential student and teacher-level predictors on students' post-instructional LPCI assessment score were studied, which was used to measure students' understanding of lunar phases content. The students participated in the integrated mathematics and science unit after their teachers had received professional developed pertaining to the REAL Curriculum; therefore, it was desirable to measure students' post-instructional scores on the LPCI assessment as a result of the student and teacher parameters that have been identified.

Given as many as 13 different measures, as can be seen in Table 3, an initial screening was first conducted on the spatial-content measures using backward elimination. Backward elimination was chosen as the initial screening process since other researchers have relied on this method to narrow down the list of possible predictors before building models (Mao, 2004; Sutter & Kalivas, 1993). Backward elimination is also beneficial in that it makes an efficient use of time; without using this process, one could have tested each individual predictor of theoretical interest and determine if was significant and/or would improve the model on a variable-by-variable basis, but this screening process provided the most efficient way to achieve the goal of answering the research question. Therefore, backward elimination was used to narrow them down to a more manageable, smaller list of candidate predictors which are most likely to contribute significantly to the prediction of the dependent variable in follow-up multilevel modeling (Micceri, 2007; Sun, Bradley & Akers, 2012).

Table 3. Description of the Measures

Measure Variable	Measure Variable Description
LPCI_Overall_S_1	Overall Student Score on the LPCI before Content was Taught
LPCI_PP_S_1	Overall Student Score on the LPCI Periodic Patterns Domain before Content was Taught
LPCI_GSV_S_1	Overall Student Score on the LPCI Geometric Spatial Visualization Domain before Content was Taught
LPCI_CD_S_1	Overall Student Score on the LPCI Cardinal Directions Domain before Content was Taught
LPCI_SP_S_1	Overall Student Score on the LPCI Spatial Projection Domain before Content was Taught
PSVT-ROT_Overall_S_1	Overall Student Score on the Purdue Visualization of Rotations Test before Content was Taught
PSVT-ROT_Overall_S_2	Overall Student Score on the Purdue Visualization of Rotations Test after Content was Taught
LPCI_Overall_T_3	Overall Teacher Score on the Purdue Visualization of Rotations Test after Content was Taught
LPCI_PP_T_3	Overall Teacher Score on the LPCI Periodic Patterns Domain after Content was Taught
LPCI_GSV_T_3	Overall Teacher Score on the LPCI Geometric Spatial Visualization Domain after Content was Taught
LPCI_CD_T_3	Overall Teacher Score on the LPCI Cardinal Directions Domain after Content was Taught

Table 3. Description of the Measures (Continued)

Measure Variable	Measure Variable Description
LPCI_SP_T_3	Overall Teacher Score on the LPCI Spatial Projection Domain after Content was Taught
PSVT-ROT_Overall_T_3	Overall Teacher Score on the Purdue Visualization of Rotations Test after Content was Taught

Note. LP = Lunar Phases Concept Inventory; Overall = Overall score on the assessment; PP = Periodic Patterns; GSV = Geometric Spatial Visualization; CD = Cardinal Directions; SP = Spatial Projection; PSVT-ROT = Purdue Visualization of Rotations Test; S = Student; T = Teacher; 1 = Before the instruction unit Was taught for students; 2 = After the instructional unit was taught for students; 3 = After the instructional unit was taught for teachers

It is important to note that student demographic variables such as gender and race/ethnicity were not included in the initial screening process since the demographic parameters would be considered during the phase in which models were physically constructed and analyzed.

At the conclusion of the initial screening process, a total of five predictors were identified as contributing most significantly to students' overall post-scores on the LPCI. To facilitate the interpretation of the intercept, the selected predictors were centered using their grand means. In Table 4, the selected predictors and their grand-mean centered variables are outlined.

Table 4. Description of Predictor Variables Centered Around Grand Mean

Measure Centered Variable	Measured Centered Variable Correction
LPCI_PP_S_1_ctr	LPCI_PP_S_1 - 26.278481
LPCI_GSV_S_1_ctr	LPCI_GSV_S_1 - 22.5316456
LPCI_CD_S_1_ctr	LPCI_CD_S_1 - 19.1898734
LPCI_SP_S_1_ctr	LPCI_SP_S_1 - 28.6708861
PSVT-ROT_Overall_S_2_ctr	PSVT-ROT_overall_S_2 - 36.460177

Note. LPCI = Lunar Phases Concept Inventory; Overall = Overall score on the assessment; PP = Periodic Patterns; GSV = Geometric Spatial Visualization; CD = Cardinal Directions; SP = Spatial Projection; PSVT-ROT = Purdue Visualization of Rotations Test; ctr = centered grand mean; S = Student; 1 = Before the instruction unit was taught for students; 2 = After the instructional unit was taught for students

It was determined that the data showed that the students within the study were nested within their teachers, so a hierarchical linear model (HLM) was considered to address the research question (Heck, Thomas, & Tabata 2013; Hox, 2010; Raudenbush & Bryk, 2002). A series of Repeated Measures ANOVA (RMANOVA) tests demonstrated that different teachers reached different gain scores with regards to their students on the LPCI assessment after instruction was taught, a hierarchal linear model was considered in which student overall LPCI scores were nested within a category where teacher identifiers were used. While this model would have been justified in its use in the study, it would have only shown that six of the seven different teachers' students achieved significantly different gain scores on the LPCI. This model could not be used to help identify associations and differences between the student characteristics and the teacher spatial-content knowledge parameters. A HLM was justified to be used by the study, but the only extra information gained could have also been shown by performing a series of RMANOVA tests since the variance between student of different teachers could not be explained. Table 5 summarizes RMANOVA tests that were conducted between pre-instructional and post-instructional student performance on the LPCI assessment organized by teacher.

Table 5. Student Scores on the LPCI by Teacher and Gender

	Group	N	Pre-Score	Post-Score	Gain	F	*P*	Partial η^2
All Teachers	All	395	22.59 (10.51)	37.89 (15.496)	15.30	376.928	0.000	0.489
	Boys	162	23.58 (11.58)	37.87 (16.24)	14.29	129.611	0.000	0.446
	Girls	233	21.91 (9.67)	37.90 (15.00)	15.99	250.141	0.000	0.519
Teacher 1	All	66	20.30 (8.94)	37.27 (14.12)	16.97	110.859	0.000	0.630
	Boys	29	21.03 (10.38)	36.03 (14.10)	15.00	41.056	0.000	0.595
	Girls	37	19.73 (7.72)	38.24 (14.25)	18.51	70.311	0.000	0.661
Teacher 2	All	70	23.57 (10.64)	39.29 (16.77)	15.72	61.120	0.000	0.470
	Boys	30	25.33 (10.82)	42.17 (18.65)	16.84	26.298	0.000	0.476
	Girls	40	22.25 (10.44)	37.13 (15.14)	14.88	34.263	0.000	0.468
Teacher 3	All	73	21.64 (10.99)	39.73 (17.04)	18.09	100.314	0.000	0.582
	Boys	30	21.67 (13.15)	43.33 (19.21)	21.66	49.509	0.000	0.631
	Girls	43	21.63 (9.37)	38.60 (15.48)	16.97	50.995	0.000	0.548

Table 5. Student Scores on the LPCI by Teacher and Gender (Continued)

	Group	N	Pre-Score	Post-Score	Gain	F	*P*	Partial η^2
Teacher 4	All	20	29.25 (12.90)	37.25 (13.33)	8.00	3.910	0.063	0.171
	Boys	10	30.50 (13.43)	33.50 (10.29)	3.00	0.343	0.572	0.037
	Girls	10	28.00 (12.95)	41.00 (15.42)	13.00	4.527	0.062	0.335
Teacher 5	All	66	22.27 (11.07)	28.11 (11.46)	5.84	12.942	0.001	0.166
	Boys	23	24.57 (12.06)	25.65 (6.96)	1.08	0.612	0.692	0.007
	Girls	43	21.05 (10.44)	29.42 (13.15)	8.37	18.654	0.000	0.308
Teacher 6	All	71	22.96 (10.16)	42.32 (14.34)	19.36	115.802	0.000	0.623
	Boys	29	22.24 (11.15)	40.17 (14.73)	17.39	57.055	0.000	0.671
	Girls	42	23.45 (9.53)	43.81 (14.05)	23.36	62.491	0.000	0.604
Teacher 7	All	29	23.10 (8.60)	43.10 (14.72)	20.00	58.000	0.000	0.674
	Boys	11	25.91 (9.17)	45.00 (16.28)	19.09	14.112	0.004	0.585
	Girls	18	21.39 (8.01)	41.94 (14.05)	20.55	47.111	0.000	0.735

Note. Four students did not take the LPCI assessment before the instructional unit was taught; one student from Teacher 3, two students from Teacher 4, and one student from Teacher 6. Group = Gender; N = Number of students; Pre-Score = Students' average pre-instructional percentage score on the LPCI assessment; Post-Score = Students' average post-instructional percentage score on the LPCI assessment; Gain = Average change in percentage score on the LPCI; F = F Statistic; p = Significance; η^2 = Non-linear correlation coefficient.

For example, refer to Teacher 7 in which all students' average pre-instructional score of 23.10% increased to a post-instructional score of 43.10%; a significant gain of 20.0% on the LPCI assessment. In contrast, refer to Teacher 5 in which all students' average pre-instructional score of 22.27% increased to a post-instructional score of 28.11%, which is only a significant gain of 5.85% on the same assessment. While significant gain scores were found for students in both teacher's classes, one cannot interpret the gains scores in a way that could be used to draw conclusions that could explain the variances that have been shown to be statistically significant.

It is also important to highlight the results from the RMANOVA test conducted for Teacher 4, which is the only teacher not found to exhibit significant differences between student pre-scores and post-scores on the LPCI; boys were shown to exhibit a 3.00 percentage point gain score and girls were shown to exhibit a 13.00 percentage point gain. While this may suggest that the instructional unit favored girls over boys in terms of student learning outcomes, it is important to note that the low number of students in the teacher's sample, 20, may have contributed to results that were not found to be significant. Even though variance exists between different students' post-instructional scores and gains from pre-instructional scores for six of the seven teachers, the HLM did not provide enough information to help explain the variance whenever the model was intended to be interpreted; in future studies, different teacher characteristics (number of years teaching, highest level of degree earned, and age) would need to be considered in an attempt to build a more robust model. Therefore, while it is acknowledged that a multi-level model would have been justified in the use of the study, the issue pertaining to explaining variance led to the construction of a series of linear mixed models.

Using the selected five predictors plus demographic variables, a mixed regression model was built to explain the variability in the overall student LPCI assessment scores after the unit was taught. The process began with the null model with no predictors in the model; in each subsequent step, more predictors were added to the model while comparing the fit of the new model with that of the preceding model. This process continued until a point was reached in which any additional predictors entered into the model were no longer able to improve its fit to the data. During the process, demographic variables were entered ahead of selected predictors. Each model's Bayesian Information Criterion was used as the measure of model fit. With the decision to pursue linear mixed model regression, four models of interest were considered based on the models' Bayesian Information Criterion (BIC) Values and the research question of the study. A summary of each considered model can be found in Table 6 along with each model's associated Bayesian Information Criterion (BIC) values.

Table 6. Summary of Constructed Models for Analysis

Model Number	Model Terms	BIC Value
1	Intercept	3265.2
2	Intercept Race	3212.8
3	Intercept Race LPCI_PP_S_1 LPCI_GSV_S_1 LPCI_CD_S_1 PSVT-ROT_Overall_S_1	3185.9

Table 6. Summary of Constructed Models for Analysis (Continued)

4	Intercept Race LPCI_PP_S_1 LPCI_GSV_S_1 LPCI_CD_S_1 LPCI_SP_S_1 PSVT-ROT_Overall_S_2	2683.3

Note. LPCI = Lunar Phases Concept Inventory; Overall = Overall score on the assessment PP = Periodic Patterns; GSV = Geometric Spatial Visualization; CD = Cardinal Directions; SP = Spatial Projection; PSVT-ROT = Purdue Visualization of Rotations Test; S = Student; 1 = Before the instruction unit was taught for students; 2 = After the instructional unit was taught for students

It is important to state that one of the goals of the study was to determine if students' pre-instructional content knowledge could be used to predict student learning outcomes; consideration of the four spatial-mathematical domains was necessary in the model construction process. However, another goal was to determine if students' general spatial ability could be used as a predictor on student learning outcomes; using the post-instructional PSVT-ROT scores allowed for the most accurate measure of a students' spatial ability at the time in which students were expected to complete the post-instructional LPCI assessment.

Based on each model's Bayesian Information Criterion (BIC) values (lowest value is best when comparing one model to another model), the fourth model was chosen to be the most desirable model in helping address the original research question.

Results

Accepted Model

The fourth model created using a linear mixed modeling approach was chosen to help answer the research question of the study. A summary of the model and its components can be found in Table 7.

Table 7. Summary of the Final Selected Model

Parameter	Model Estimate	Parameter	Model Estimate
Intercept	39.1679***	Race – Declined to Answer	1.7612
Race – African (Not American)	3.7089	Race – White, Non-Hispanic	0
Race – African American	-4.1418	LPCI_PP_S_1	0.1551***
Race – Asian (Not American)	1.5279	LPCI_GSV_S_1	0.02382
Race – Asian American	-0.6715	LPCI_CD_S_1	0.07918
Race – Hispanic American	-3.9145	LPCI_SP_S_1	0.08700*
Race – Native American	-1.9693	PSVT-ROT_overall_S_2	0.2030***
Race - Other	-5.4638*		

Note. LPCI = Lunar Phases Concept Inventory; PP = Periodic Patterns; GSV = Geometric Spatial Visualization; CD = Cardinal Direction; SP = Spatial Projection; PSVT-ROT = Purdue Visualization of Rotations Test; S = Student; 1 = Before the instruction unit was taught; 2 = After the instructional unit was taught
* $p<.05$.** $p<.01$.*** $p<.001$.

A discussion of each tested parameter contained within the model is as follows.

Student Demographics

1. **Race/Ethnicity**

The model chosen for analysis shows that the different races under consideration were not found to be significant predictors of students' overall scores on the overall LPCI assessment, at the 95% confidence level, after instruction was taught except for the category in which students self-identified themselves a race of "Other". According to the chosen model, on average, the difference in the overall LPCI score after the instructional unit has been taught between a student who identifies as "Other" and a White, Non-Hispanic student is - 5.4638% points; on average, a student who identifies as "Other" will have scored 5.4638% points lower on the overall LPCI assessment after the instructional unit has been taught for every 1.0000% point earned by a White, Non-Hispanic student when controlling for the four LPCI spatial-mathematical domain scores before the instructional unit has been taught and the scores on the PSVT-ROT after the instructional unit was taught.

2. Gender

In each of the four models that were considered for this study, the student demographic of gender was not included; the genders of the students who participated in this study were not found to offer significant explanatory power within the model constructs. Each of the four models constructed for analysis provided a better fit whenever the student demographic of gender was not included in the models.

Student Level Predictors

1. Spatial and Mathematics Domain: Periodic Patterns

According to the model under consideration, the predictor variable of student scores on the LPCI assessment domain of Periodic Patterns before the instructional unit was taught was found to be statistically significant at the 95% confidence level. For a group of students from the same race category and who are also identical on the overall PSVT-ROT score after the instructional unit has been taught, it is estimated that, given a 1.0000% point increase on the LPCI assessment domain of Periodic Patterns before the instructional unit was taught, their overall LPCI assessment score after the instructional unit has been taught is expected to increase by 0.1551% points, on average when all other spatial-mathematical domains are held constant.

2. Spatial and Mathematics Domain: Geometric & Spatial Visualization

When considering the second spatial and mathematics domain, the predictor variable of student scores on the LPCI assessment domain of Geometric Spatial Visualization before the instructional unit was taught was not found to be statistically significant. However, keeping this predictor variable in the chosen model allowed for the lowest Bayesian Information Criterion (BIC) Values.

3. Spatial and Mathematics Domain: Cardinal Directions

The predictor variable of student scores on the LPCI assessment domain of Cardinal Directions before the instructional unit was taught was not found to be statistically significant. However, as with the spatial-mathematics domain of Geometric Spatial Visualization, keeping this predictor variable in the chosen model allowed for the lowest Bayesian Information Criterion (BIC) Values.

4. Spatial and Mathematics Domain: Spatial Projection

According to the model under consideration, the predictor variable of student scores on the LPCI assessment domain of Spatial Projection before the instructional unit was taught was found to be statistically significant. For a group of students from the same race category and who are also identical on the overall PSVT-ROT score after the instructional unit has been taught, it is estimated that, given a 1.0000% increase on the LPCI assessment domain of Spatial Projection before the instructional unit was taught, their overall LPCI assessment score after the instructional unit has been taught is expected to increase by 0.08700% points, on average when all other spatial-mathematical domains are held constant.

5. The Purdue Visualization of Rotation Test

The last student predictor under consideration is how students performed on the PSVT-ROT after instruction was taught. This predictor was found to be a statistically significant predictor. For a group of students from the same race category and who are also identical on the spatial-mathematical domains on the LPCI assessment score before the instructional unit has been taught, it is estimated that, given a 1.0000% point increase in overall the PSVT-ROT, their overall LPCI assessment score after the instructional unit has been taught is expected to increase by 0.2030% points, on average when all spatial-mathematical domains are held constant.

Teacher Level Predictors

Similar to the findings with students' gender and its impact on students' scores on the overall LPCI assessment after instruction had been implemented in the classroom, in each of the four models that were considered for this study, none of the teacher spatial-content knowledge parameters were included in the models; teachers' scores on the two assessments at any of the three times in which they were tested were not found to be associated with the student learning outcomes.

Discussion and Limitations

Student Demographics

1. Gender

Based on the model used to answer the research question, a student's gender was not found to be a significant predictor of students' overall score on the LPCI assessment, which is contrary to the findings of studies that have shown that gender is associated with a student's spatial ability (Ben-Chaim, Lappan, & Houang, 1988; Battista, 1990; Casey, Nuttall, Pezaris, & Benbow, 1995; Linn & Petersen, 1985; Lippa, Collaer, & Peters, 2010; Voyer, Voyer, & Bryden, 1995), which is necessary to understand the phases of the Moon (Jackson et al., 2015; Wilhelm, 2009; Wilhelm et al., 2013a; Wilhelm et al., 2013b; Wilhelm, Toland, & Cole, 2017). When viewing the results of RMANOVA tests that were conducted and organized in Table 5, girls were shown to have an average pre-score on the LPCI of 21.91% while boys had a pre-score of 23.58%; boys outscored girls on the pre-LPCI assessment even though the results were not found to be statistically significant. Post LPCI score analysis shows that girls scored 37.90% while boys scored 37.87%; girls were able to achieve a higher average gain score for the LPCI of 15.99% while boys gained 14.29% even though the results were not found to be statistically significant. Even if gender was not found to be a significant predictor of students' overall LPCI score since girls and boys only differed by 0.03% in LPCI post-score results, the data suggests that girls potentially benefitted from project based instruction by allowing them to slightly outscore, even if non-significantly, their boy peers.

It must be stated that Wilhelm (2009) concluded in her study that the implementation of the REAL Curriculum helped close the gender gap from pre-instruction to post-instruction even though girls scored lower than boys on every domain that was measured before instruction was implemented. At the end of the study, Wilhelm (2009) showed that girls made gains that brought each of their spatial-mathematical domains up to or exceeding their boy peers, which is also in agreement with the results of this study. The study conducted by Wilhelm, Toland, and Cole (2017) did show that, overall, a gender gap existed between boys' and girls' overall pre-instructional LPCI scores, but the implementation of the REAL Curriculum afforded girls opportunity to make significant gains on lunar phases understanding; gain scores by white girls were higher than white boys on the overall LPCI and on the spatial-mathematical domains of Period Patterns and Spatial Projection whenever the treatment groups were considered. However, black girls receiving BAU instruction were shown to have lower gain scores than boys of color receiving BAU instruction on the overall LPCI and the spatial-mathematical domains of Periodic Patterns, Geometric Spatial Visualization, and Spatial Projection. When considering overall girls, however, the gains scores made by females were much higher than the gain scores by boys when comparing treatment instruction with BAU instruction; girls increased their understanding of lunar phases within project based instructional environments more than in traditional learning environments.

A possible reason that gender was not found to be a significant predictor of students' overall score on the LPCI may be due in part to the fact that teachers received professional development involving the REAL Curriculum, which specifically highlighted the need for teachers to provide instruction that "has shown [that] students (especially females) benefit greatly from situated, project-enhanced learning experiences (Boaler, 2002; Morrow & Morrow, 1995)…" (Wilhelm, Toland, & Cole, 2017, p. 47). Therefore, it is argued that the implementation of the REAL Curriculum may have resulted given boys and girls opportunities to increase their understanding of lunar phases in approximately equal ways leaving no statistical difference between student performance on the post-LPCI assessment.

There are limitations to this study which need to be acknowledged. By referring to Table 5, it can be shown that different teachers provided instruction that showed significant differences in post-instructional scores and gain scores when considering gender. Teacher 5 showed the largest statistical difference in LPCI gain score by gender, but Teacher 2 showed the smallest difference in LPCI gain score by gender. This study does not factor teacher autonomy in the way in which they structured their classes and taught the lessons within the instructional unit. With these differences acknowledged, the data does not provide an explanation of the variances found by performing the RMANOVA tests. It must be emphasized that future studies would need to be conducted that can be used to provide an analysis of the specific instructional methods used by each teacher in this study; filming instructional lessons, transcribing the videos, and developing a coding scheme would provide a qualitative approach to help provide a view into the instructional approaches that are used in the classroom that potentially address the gender gap.

2. Race/Ethnicity

The model used for analysis indicated that only a students' classification of "Other" for her or his race was found to be a significant predictor in student performance on the overall LPCI post-score. This finding runs in opposition with the existing literature that addresses the race/ethnicity student demographic. Based on Campbell's (1989) and Manning's (1998) argument that future researchers should consider racial differences when conducting studies pertaining to gender and academic performance on mathematics and science assessment, it was important to include this student demographic in order to add to the limited existing research on the subject. Most of the existing studies indicate that White, Non-Hispanic students consistently score higher than students who have been classified into traditional minority groups within various subjects and content areas (Lee, 2004; Lee & Wong, 2004; Lubienski, 2002; McGraw, Lubienski, and Strutchens, 2006; Reyes & Stanic, 1988; Wilhelm, 2013a; Wilhelm, 2013b; Wilhelm, Toland, & Cole, 2017). In Jackson et al.'s study (2015), students of color received instruction pertaining to the phases of the Moon; a control group received traditional instruction and an experimental group received project based instruction. The findings of the study showed that students of color within the experimental group achieved higher overall gain scores on the PSVT-ROT, which suggests a race/ethnicity performance gap was narrowed within the study. While the results of this study cannot make the claim that a race/ethnicity gap was closed as a result of implementing project based instruction, it may be possible that the implementation of the REAL Curriculum within this study allowed students in all but one of the race/ethnicity categories to achieve post LPCI scores that were statistically insignificant from scores achieved by White, Non-Hispanic students.

The study conducted by Wilhelm, Toland, and Cole (2017) showed that boys of color within the treatment group achieved higher gain scores than boys of color within the BAU group on the overall LPCI, and on the spatial-mathematical domains of Geometric Spatial Visualization and Spatial Projection. The same trend was also found when comparing results on the PSVT-ROT. Girls of color in the treatment group achieved higher gain scores on the LPCI than girls of color in the BAU group on the overall assessment, and on the spatial-mathematical domains of Periodic Patterns, Geometric Spatial Visualization, and Spatial Projection. Much like comparing instruction regarding boys of color, girls of color receiving treatment instruction had higher gains on the PSVT-ROT than girls of color receiving BAU instruction. The findings in this study are further evidence that implementing project based instruction using the REAL Curriculum allows girls and boys of color to possibly gain a more sophisticated understanding of lunar phases after instruction than when compared to similar students receiving traditional instruction. Since the REAL Curriculum was used to implement instruction pertaining to lunar phases, it is possible that students' overall LPCI post-scores were not found to be statistically different from each other except in the case in which students self-identified themselves as other.

The finding that none of the race/ethnicity categories were found to be statistically significant when predicting student learning outcomes, except in the case in which students selected "Other", is one that would seem to be contrary to the research that exists that shows that White, Non-Hispanic students have statistically significant differences in learning outcomes than students of other races/ethnicities. By referring to Table 2, it can be seen that students were given the option to select from one of nine possible choices for their race/ethnicity. With so many options for students to choose from, it can be seen from Table 2 that some of the race/ethnicity choices resulted in a small student populations; four students indicated that they were African (Not American), six students indicated that they were Native American, and twenty two students indicated that they were Hispanic American. With such a low student population numbers within each category, it is possible that there were not enough students in each category to provide a potentially more reliable result. Matters are further complicated when it is acknowledged that students were not given an explicit option to indicate that they are a mixture of races/ethnicities. While "Other" was intended to include students of mixed races, one cannot assume the full intent of the students who selected "Other"; the option may have been representative of "mixed" in the minds of some of the students, but this could only be confirmed with follow up interviews with students so that they could explain their rationale for selecting "Other". This point can be further complicated when it may not have been safe to assume that students would correctly know the difference between "African American" and "African" or "Asian American" and "Asian". To improve on this possible issue, it would be suggested that future studies reduce the number of category options for students or change the categories to be more inclusive of the student population under consideration; adding a "Mixed Race" category and combining "Asian" and "Asian" into an "Asian Heritage" category, for example may alleviate potential problems. Even with combined categories within future studies, larger population numbers for each race/ethnicity category are necessary; the low population numbers for each race/ethnicity category made it difficult to conduct meaningful RMANOVA tests that were conducted in the case of analyzing gender differences.

Student Spatial Ability & The Connection to Lunar Phases

Current research exists that draws connections between a students' understanding of lunar phases and a students' spatial ability (Ashmann, 2012; Cole, Wilhelm, & Yang, 2015; Coluccia & Louse, 2004; Jackson et al., 2015; Plummer, 2014; Plummer, 2015; Plummer, Bower, & Liben, 2016; Sherrod & Wilhelm, 2009; Udomprasert et al., 2016; Wilhelm, 2009; Wilhelm, 2014a; Wilhelm et al., 2013a; Wilhelm et al., 2013b; Wilhelm, Toland, & Cole, 2017). The connections that have been highlighted are the same connections that have been used to guide this study; the referenced texts are mostly in agreement with the chosen model that was used to answer the research question. Two of the four spatial-mathematical domains on the LPCI pre-assessment and students' scores on the PSVT-ROT post-assessment were found to be significant predictors of students' overall scores on the LPCI post-assessment.

Wilhelm's four spatial-mathematical domains have been argued to be important components of students' understanding of lunar phases. Therefore, it was expected that the four spatial-mathematical domains would be significant predictors of students' understanding of the lunar phases. What was not expected, however, was that the chosen model used for analysis showed that Periodic Patterns and Spatial Projection were significant predictors of students' understanding of the Moon's phases while the two spatial-mathematics domains of Geometric Spatial Visualization and Cardinal Directions were not found to be significant predictors of students' performance on the LPCI post-assessment.

One of the four spatial-mathematical domains identified that was found to be significant a significant predictor was Periodic Patterns. Recall that Periodic Patterns refers to the concept of a process or an event occurring at regular intervals of time and/or space such as how the phases of the Moon occur at interval times within an entire lunar cycle. Since observations have shown that the Moon's phases occur within a predictable cycle approximately every 29.53 Earth days, it can be argued that it is critical for students to gain an understanding of the Periodic Patterns domain before understanding the patterns that occur within a lunar cycle. It is expected, then, that a students' ability to identify and understand Periodic Patterns before any instruction was implemented in the classroom would be a significant predictor in how well a student performs on an assessment; an assessment that contains questions pertaining to different points in time in which the Moon is going through one of its cycles. By knowing how to identify and understand the concept of periodicity of lunar phases before receiving instruction, it can be suggested that students may have been able to draw connections between their initial understanding and the content taught by their teacher; without knowing the skills associated with identifying a Period Pattern, students may have initially struggled in even recognizing that the Moon exhibits predictable behavior throughout its entire cycle.

The other domain that was found to be a significant predictor is Spatial Projection. Remember that Spatial Projection refers to a students' ability to project herself/himself at a different Earthly location and visualizing the Moon's appearance from that location; students who are able to spatially project are students who are able to place themselves in locations within the frame of reference of the Earth. Therefore it was expected that a students' initial ability to view the Moon from different locations on the Earth's surface would benefit them on developing a robust understanding of the phases of the Moon after instruction was implemented. Based on this study, even before receiving instruction, students who are able to place themselves at different points along the Earth's surface and mentally picturing the shape and orientation of the illuminated portion of the Moon are shown to have an advantage over a comparable student who did not initially possess the skill. Since a number of questions on the LPCI depend on this skill, it can be suggested that students who were initially able to demonstrate the skill may have further reinforced or strengthened the skill as a result of receiving instruction from their teachers.

The two spatial-mathematical domains that were not found to be significant predictors are Cardinal Directions and Geometric Spatial Visualization. Cardinal Directions relies on a student's ability to determine an object's vector direction from a given position (i.e., North, South, East, West, etc.) while Geometric Spatial Visualization requires that students be able to visualize the geometric spatial features of the Sun-Moon-Earth system as it appears in space above/below/within the Moon/Earth/Sun plane. It is important to restate that these parameters were measured before the students received instruction pertaining to the phases of the Moon; it is possible that students were able to develop these skills and strengthen these skills as a result of the instruction implemented in their classroom, but one cannot state that a student who were able to demonstrate either or both of these skills would have an advantage over the same type of student who could not demonstrate these skills. It could be possible that the student population under consideration, overall, possessed these skills at the same level or degree before instruction took place in the classroom; the students may have been approximately equal in these two domains, which may have made it difficult to measure if they were significant predictors for student success on the overall LPCI assessment after instruction took place.

The PSVT-ROT was a second assessment given to students, but was administered to the students after instruction took place. The model used within the study states that students' performance on this assessment, after instruction has been implemented, is a significant predictor in students' scores on the overall LPCI assessment after instruction takes place. Bayraktar (2009) stated that an understanding of revolving and rotating objects is important in a students' understanding of the celestial motion of the objects within a Sun-Earth-Moon system. Therefore, it is expected that a student who has been shown to possess the skill to mentally rotate and revolve irregular geometric shapes would also be able to perform well on tasks that involve the mental rotation and revolution of the Sun, Earth, and Moon in order to understand the phases of the Moon. Since this parameter was measured after instruction took place, one could suggest that the skill of mentally rotating and revolving irregular shapes objects may have developed in some students and strengthened in others as a result of the instruction implemented by their teachers. Students who developed or strengthened this spatial ability skill may have made connections between rotating and revolving actual objects such as the celestial objects involved in the Sun-Earth-Moon system and rotating and revolving abstract irregular shapes that are found on the PSVT-ROT. If, as a result of instruction, students were not able to develop or strengthen the skill of mentally manipulating the orientation of irregular geometric shapes, it is reasonable to think that real life cases, such as objects within a Sun-Earth-Moon system, would be difficult for students. Regardless, the fact that the students' post scores on the PSVT-ROT were found to be a significant predictor of students' understanding of lunar phases reinforces the educational research that a link exists between a students' performance on the LPCI and a students' spatial ability (Ashmann, 2012; Cole, Wilhelm, & Yang, 2015; Coluccia & Louse, 2004; Jackson et al., 2015; Plummer, 2014; Plummer, 2015; Plummer, Bower, & Liben, 2016; Sherrod & Wilhelm, 2009; Udomprasert et al., 2016; Wilhelm, 2009; Wilhelm, 2014a; Wilhelm et al., 2013a; Wilhelm et al., 2013b; Wilhelm, Toland, & Cole, 2017).

A Distinct Study

This study is within a unique group of related studies that are among the first research studies that examine students' spatial-content knowledge as they participate in Earth/Space science units.

In agreement with Wilhelm, Toland, and Cole (2017), this study is notable in that student race/ethnicity is also considered in an attempt to develop an understanding of how students' understanding of lunar phases and its connection with spatial ability. Even if limitations exist within the data concerning this specific student demographic, it is notable that all but one of the race/ethnicity categories ("Other") were not found to be significant predictors of students' understanding of lunar phases. While studies have been highlighted to show that performance gaps exist between students of color and White, Non-Hispanic students, this study is in agreement with other studies (Jackson et al., 2015; Wilhelm, Toland, & Cole, 2017) that have shown that the implementation of the REAL Curriculum has shown to provide students of color with the experiences necessary to make similar or higher gains than White, Non-Hispanic students. Since all students of different races/ethnicities, excluding students who self-identified as “Other”, were found to achieve similar scores on the LPCI post-assessment, evidence does exist to possibly suggest that implementing project based instruction benefits all students – especially students of color.

This study is also unique in that statistical analysis of the chosen linear mixed model showed that gender was not a significant predictor in student learning outcomes when teachers delivered instruction based on the REAL Curriculum. While the literature is small, studies do exist to show that providing girls with project based instructional strategies to learn the phases of the Moon benefits them to a significant degree (Wilhelm, 2009; Jackson et al., 2015; Wilhelm, Toland, & Cole, 2017). This study further reinforces the notion that girls exposed to REAL Curriculum provides girls and boys with instruction that allow them to reach an understanding of lunar phases such that the scores of both groups are not statistically different from each other; the implementation of this curriculum actually allowed girls, overall, to make higher gains in their understanding of lunar phases than boys.

Furthermore, this study suggests that a students’ pre-instructional spatial ability pertaining to Period Patterns and Spatial Projection may give comparable students an advantage of learning about lunar phases when other student and teacher parameters are held constant. In agreement with Wilhelm’s (2009) conceptual framework and “that one must have well-developed spatial skills in order to understand astronomical phenomena such as lunar phases” (Wilhelm, Toland, & Cole, 2017, p. 50), studies such as this can be used to help construct and/or implement more effective strategies that help promote student spatial ability and content knowledge in an effort to close a potential gender gap in student performance, close a potential race/ethnicity gap in student performance, and positively influence students who can then become productive citizens of the twenty first century.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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