FACTORS INFLUENCING MIDDLE SCHOOL STUDENTS' SPATIAL MATHEMATICS DEVELOPMENT WHILE PARTICIPATING IN AN INTEGRATED STEM UNIT

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This study examined differences between two groups of students' spatial-scientific reasoning from pre to post implementation of an Earth/Space unit. Using a quasi-experimental design, researchers explored how instructional method and gender affected learning. Treatment teachers employed an integrated STEM curriculum while the control teacher implemented her regular Earth/Space unit. The Geometric Spatial Assessment (GSA), the Purdue-Spatial Visualization Rotation Test, and the Lunar Phases Concept Inventory (LPCI) were used to assess learning. Experimental groups made gains on periodicity LPCI domains while the control made gains on geometric spatial visualization LPCI domains. Only females made gains on GSA items. This is the first quasi-experimental study to examine students' spatial reasoning as they participate in Earth/Space units and to discover gender's role in this spatial development.

Keywords: Spatial Visualization; Sex Differences; Middle School; STEM Integrated Curriculum

Objective and Theory

Research studies have shown links between students' spatial reasoning ability and their understanding of scientific phenomena (Rudmann, 2002; Black, 2005). This is particularly true in the areas of Earth/Space phenomena. For example, Rudmann (2002) found that students' propensity to learn scientific explanations for phenomena such as the cause of the seasons was limited by their spatial aptitude. Similarly, Wellner (1995) reported that students were more likely to describe a correct cause of lunar phases when they had a strong spatial sense. Black (2005) claimed that "mental rotation is the most important in understanding Earth science concepts that are associated with common misconceptions … humans are handicapped by their single vantage point from Earth of the moving bodies in outer space" (p. 403).

We claim that one cannot understand many astronomical concepts without a developed understanding of four spatial mathematical domains defined as follows: (1) *Geometric Spatial Visualization*—Visualizing the geometric spatial features of a system as it appears above, below, and within the system's plane; (2) *Spatial Projection*—Mentally projecting to a different location on an object and visualizing from that global perspective; (3) *Cardinal Directions*—Distinguishing directions (N,S,E,W) in order to document an object's vector position in space as a function of time; and (4) *Periodic Patterns*—Recognizing occurrences at regular intervals of time and/or space.

The *Geometric Spatial Visualization* domain also involves *mental rotation* since as one visualizes a system, such as the Moon/Earth/Sun, one must consider and manipulate the motion of the system itself. *Spatial Projection* has a mental rotation derivative as well since one must mentally maneuver the sky throughout a day's viewing due to Earth's rotation.

Research on students' understanding of spatial concepts shows gender differences. Kerns and Berenbaum (1991) reported that males performed better than females on spatial tests and outcomes were significantly different in the area of 3D mental rotations (p. 391). Silverman, Choi, and Peters (2007) conducted a study that assessed the universality of sex related spatial competencies. They found that men scored significantly higher than women on a 3D mental rotations test in all ethnic groups with 40 countries participating in their research study.

Not only has literature shown gender differences on spatial assessments (in favor of males), but one study conducted by Rahman and Wilson (2003) also found significant main effects of gender and sexual orientation. Large differences were found on mental rotation spatial assessments between male groups in favor of heterosexual men while modest differences were found between female groups favoring homosexual women. Rahman and Wilson claimed "variations in the parietal cortex between homosexual and heterosexual persons" explained the results (p. 25).

Previous research on gender differences on spatial assessments were conducted by the first author. Wilhelm (2009) found that pre-teen female students scored significantly lower than pre-teen male students on spatial pre-tests. However, following an intervention that utilized integrated STEM curricula with many opportunities to experience 2D and 3D stimuli, females achieved significantly higher gain scores than their male counterparts. The study speculated that the initial sex differences (on pretests) could be explained by the faster maturation (during preteen years) of the male brain's anatomical regions that handle spatial visual reasoning (Giedd et al., 1999). The implication of the study was that the 2D and 3D instructional intervention allowed females to develop their spatial skills resulting in significant achievement.

This study builds on earlier research conducted by Wilhelm (2009) and examines differences between two groups of sixth-grade students' mathematical spatial reasoning and scientific knowledge from pre to post implementation of Earth/Space units. Using a quasi-experimental design, researchers evaluated how the curricular choice and instructional method affected learning outcomes. Treatment teachers employed an integrated STEM curriculum while the control teacher implemented her regular Earth/Space unit. Differences in understanding by gender groups were also investigated within and between control and experimental groups.

Participants

Research subjects were sixth-grade students from a south-central US school. The school's demographic make-up was 84% White, 7% Black, 3% Hispanic, 3% Asian, and 3% Other; and 25% eligible for reduced-price lunches. One sixth-grade group (*N* = 70), taught by Ms. Glover (29 years experience), served as the control group. The experimental group (*N* = 124) was taught by two teachers (Ms. Stevens and Ms. Castle) with 3 and 8 years teaching experience, respectively. Both groups studied Earth/Space concepts related to the Solar System within their units. Treatment teachers employed an integrated NASA-based curriculum over a six-week period while the control teacher implemented her regular Earth/Space lessons for the same time duration. This was the first time that the NASA-based curriculum was being implemented by teachers in this state. Table 1 outlines the time spent on Earth/Space content by each (control/experimental) group, the content implemented, and the instructional format.

Table 1: Unit Timeline by Group with Lesson Content and Method of Implementation

Week	Control Teacher		Experimental Teachers (with NASA-based curriculum)	
	Lesson Topics	**Method**	**Lesson Topics**	**Method**
Week 1	How Planets Compare in Size with Sun?	Video (NASA Cosmic Voyage) Fill in blank Worksheet Mnemonics	*Overview of Universe** Why does the Moon appear to change its shape?	Poster Project "Many Moons" by Thurber, Moon Journaling (five weeks) Stellarium (planetarium software)
Week 2	Sun and Stars	Video Reading Note Taking PPT	How do I measure the distance between objects in the sky? Altitude and Azimuth Angles	Measurement and graphing
Week 3	Rotation/Revolution and Predictable Motions	PPT Worksheet	How can I say where I am on the Earth? Introduction to Longitude/Latitude	Longitude and Latitude Worksheet
			*Rotation/Revolution and Seasons**	PPT Modeling Activity

Week	Control Teacher		Experimental Teachers (with NASA-based curriculum)	
	Lesson Topics	**Method**	**Lesson Topics**	**Method**
Week 4	Moon Phases	PPT & Worksheet Phase Animations 3D Activity of Earth/Moon/Sun system for various phases	What can we learn by examining the Moon's surface?	Exploration of Lunar Images
Week 5	Eclipses and Seasons	Videos & Worksheet Mnemonics	Scaling Earth/Moon/Mars	PPT Scaling Activity using Balloons
Week 6	Tides and Planets Review	Video –(Tides; Sun/Earth/Moon) Planets Scavenger Hunt PPT	Modeling Earth/Moon/Sun System for various phases *Tides**	PPT 3D Modeling Activity

** Not part of the NASA-based curriculum*

Research Methods

This research focused on the development of students' mathematical spatial reasoning and scientific content knowledge from pre to post unit implementation. Students were assessed pre and post intervention via survey responses given to experimental and control science classes. Table 2 outlines each of the research questions pursued and data collection method.

Table 2: Research Questions and Methods of Data Collection and Instrumentation

Research Questions	Data Collection and Instrumentation
What science and spatial content knowledge and skills will students develop through Earth/Space unit experiences? *How will Earth/Space curricular choice and instructional method affect students' learning outcomes?* *What gender differences will be observed in learned science and spatial content knowledge and skills within and between the control and experimental groups?*	Pre and Post Content Surveys: – Lunar Phases Concept Inventory (LPCI) – Geometric Spatial Assessment (GSA) – Purdue Spatial Visualization-Rotation Test (PSVT-Rot)

This quasi-experimental study utilized quantitative measures to document students' understanding before and after project implementation. The quantitative data sources used to assess students' pre and post understandings were the Lunar Phases Concept Inventory (Lindell & Olsen, 2002), a multiple-choice survey which assessed eight science domains as well as four spatial domains (Table 3); the Geometric Spatial Assessment (Wilhelm, 2009), a multiple-choice survey which assessed the same four spatial domains (Table 3); and the Purdue Spatial Visualization-Rotation Test, which assisted with diagnosing the level of students' mental rotation reasoning (Bodner & Guay, 1997).

Table 3: Concept Domains: LPCI Science Domains and Corresponding GSA Math Domains

LPCI Scientific Domains	GSA Mathematics Domains
A - Period of Moon's orbit around Earth B - Period of Moon's cycle of phases	Periodic Patterns (*occurring at regular intervals of time and/or space*)
C - Direction of the Moon's orbit around Earth E - Phase due to Sun/Earth/Moon positions G - Cause of lunar phases	Geometric Spatial Visualization (*visualizing the geometric spatial features of a given system as it appears in space above/below/within the system's plane)*
D - Moon Motion from Earthly Perspective F - Phase-location in sky-time of observation	Cardinal Directions (*documenting an object's vector direction in space as a function of time from a given position*)
H - Effect of lunar phase with change in Earthly location	Spatial Projection (*projecting one's self to a different location and visualizing from that global perspective)*

A one-way analysis of variance (ANOVA) was conducted on pre-test scores to determine if there were significant differences between control and experimental groups and between gender groups. A repeated measures ANOVA (RMANOVA) was also conducted with the factor being gender and the dependent variables being pre/post scores, and again with the factor being control/experimental group with pre/post scores as dependent variables. This was conducted for each domain within each assessment as well as for the overall scores of each assessment.

Data and Analysis

Assessments

All quantitative assessments were given to both the experimental and control groups immediately prior to and at the conclusion of their Earth/Space unit implementation. Reliability was calculated using the Cronbach's alpha; this measures the instrument's internal consistency. The coefficient alpha was calculated for 0.72, 0.79, and 0.53 for the LPCI, the PSVT-Rot, and the GSA assessments, respectively. LPCI and PSVT-Rot values were high and acceptable; the GSA value was considered moderately acceptable. The control group scored significantly higher on all content pretests than the experimental group (Table 4). No significant differences between male and female groups were observed within the control group or the experimental group on the pre-tests for the LPCI, PSVT, or GSA.

Table 4: Percentage Correct on Pre-Assessments for Control and Experimental Groups Showing Control Group Scoring Significantly Higher than Experimental on All Assessments

Assessment	*n*	Con All Pre (SD)	*n*	Exp All Pre (SD)	*p* value	*n*	Con Male Pre (SD)	*n*	Exp Male Pre (SD)	*p* value	*n*	Con Female Pre (SD)	*n*	Exp Female Pre (SD)	*p* value
LPCI	66	26.6 (14.1)	124	21.2 (9.20)	0.002*	37	27.6 (14.8)	68	21.5 (8.68)	0.009*	29	25.2 (13.6)	56	20.9 (9.87)	0.101
GSA	58	46.3 (16.1)	124	41.0 (13.6)	0.022*	27	47.2 (15.1)	64	42.5 (15.0)	0.173	31	45.6 (17.0)	60	39.5 (11.9)	0.05*
PSVT-ROT	70	43.7 (20.2)	111	35.6 (17.4)	0.005*	35	45.9 (22.8)	61	38.4 (17.1)	0.075	35	41.6 (17.1)	50	32.2 (17.2)	0.015*

* $p < 0.05$

LPCI Results

Control. The LPCI pre/post tests were given to 66 control students. A RMANOVA revealed a significant increase in the mean values from pre (26.6%) to post (38.5%) on overall test scores, $F(1, 65) = 48.1$, $p < 0.001$, partial $\eta^2 = 0.422$. The significant gain scores for control males and control females were 11.3% and 12.7%, respectively.

Experimental. The LPCI pre/post tests were given to 124 experimental students. A RMANOVA revealed a significant increase in the mean values from pre (21.2%) to post (33.7%) on overall test scores, $F(1, 123) = 72.7$, $p < 0.001$, partial $\eta^2 = 0.371$. The significant percentage gain scores for experimental males and control females were 12.1% and 13.0%, respectively. Table 5 illustrates gain scores by domain for each group.

To test for significant differences from pre to post on individual science domains, a RMANOVA was conducted for the control and experimental groups. Table 5 displays the percentage correct on each science domain. Results included experimental males achieving nearly triple the significant gains of the control males on Domain A (*orbital period*). Experimental females also made a significant gain on Domain A from pre to post whereas the control females did not. Domain B (*phase cycle period*) showed only experimental males with gain scores and Domain C (*orbital direction*) showed both control and experimental females and experimental males with significant gain scores. Only the control group made significant gains on Domain E (*phase and Sun/Earth/Moon positions*).

Table 5: Percentage Correct on Pre and Post LPCI by Science Domain for Control and Experimental Gender Groups

Science Domain	Con Male Pre (SD)	Con Male Post (SD)	Con Male Gain n =37	Con Female Pre (SD)	Con Female Post (SD)	Con Female Gain n =29	Exp Male Pre (SD)	Exp Male Post (SD)	Exp Male Gain n =68	Exp Female Pre (SD)	Exp Female Post (SD)	Exp Female Gain n =56
A-Period of Moon's orbit around Earth	29.7 (34.3)	43.2 (41.1)	13.5	24.1 (39.2)	43.1 (39.5)	19.0	16.9 (29.4)	46.3 (38.0)	29.4**	11.6 (23.3)	37.5 (38.4)	25.9**
B-Period of Moon's cycle of phases	30.6 (28.7)	43.2 (27.1)	12.6	34.5 (30.2)	46.0 (27.3)	11.5	30.9 (29.0)	45.6 (27.6)	14.7**	28.6 (28.0)	39.3 (29.2)	10.7
C-Direction of the Moon's orbit around Earth	41.9 (38.2)	55.4 (36.9)	13.5	24.1 (31.7)	53.5 (44.2)	29.4**	41.1 (37.6)	72.1 (36.0)	31.0**	41.1 (33.2)	79.5 (31.3)	38.4**
D-Motion of the Moon	37.8 (39.8)	37.8 (39.8)	0.00	32.8 (33.5)	34.5 (38.0)	1.70	19.1 (30.0)	26.5 (31.7)	7.40	27.7 (35.6)	37.5 (36.0)	9.80
E-Phase and Sun/Earth/Moon positions	31.5 (27.2)	55.9 (36.1)	24.4**	23.0 (28.3)	49.4 (37.4)	26.4**	19.1 (20.2)	27.0 (28.9)	7.90	19.6 (24.4)	24.4 (27.3)	4.80
F-Phase-Location in sky/time of observation	10.8 (15.8)	11.7 (21.1)	0.90	14.9 (19.1)	11.5 (20.5)	-3.4	9.31 (19.0)	7.35 (16.1)	-1.96	11.9 (19.5)	14.3 (21.9)	2.4
G-Cause of lunar phases	20.3 (27.5)	27.0 (30.3)	6.70	19.0 (28.1)	25.9 (36.9)	6.90	12.5 (21.8)	24.3 (37.1)	11.8	9.82 (22.2)	19.6 (31.2)	9.78
H-Effect of lunar phase with change in Earth location	12.2 (27.4)	28.4 (38.3)	16.2	20.7 (28.4)	36.2 (42.0)	15.5	13.9 (24.2)	19.1 (30.0)	5.20	12.5 (23.8)	20.5 (34.1)	8.00

$^{**}p < 0.001$

GSA Results

Control. The GSA pre/post tests were given to 58 control students. A RMANOVA revealed a significant increase in the mean values from pre (46.3%) to post (52.0%) on overall test scores, $F(1, 57) = 9.005$, $p = 0.004$, partial $\eta^2 = 0.136$. A RMANOVA also revealed a significant increase (7.5%) in the control female mean values from pre to post on overall test scores, $F(1, 30) = 10.7$, $p = 0.005$, partial $\eta^2 = 0.234$. Control males did not achieve a significant increase in scores.

Experimental. The GSA pre/post tests were given to 124 experimental students. A RMANOVA revealed a small significant increase in the mean values from pre (41.0%) to post (43.5%) on overall test scores, $F(1, 123) = 4.107$, $p = 0.045$, partial $\eta^2 = 0.032$. Like the control group, a RMANOVA revealed a significant increase (4.6%) in the experimental female mean values from pre to post on overall test scores, $F(1, 59) = 8.434$, $p = 0.005$, partial $\eta^2 = 0.125$. Experimental males showed no significant gains.

To test for significant differences from pre to post on individual spatial domains, a RMANOVA was conducted for the control and experimental groups (Table 6). Results show control females achieved significant gains on *Periodic Patterns* and *Geometric Spatial Visualization* whereas experimental females made a significant gain on *Cardinal Directions*. No male groups made significant gains on any GSA domain. Similar to Wilhelm's previous study, females in both control and experimental groups scored lower (not significantly) than their male counterparts on three of the four spatial domains on the pre-tests; and by the time of the post-tests, females ended with higher post-scores on three of the four spatial domains (see Table 6).

Table 6: Percentage Correct on Pre and Post Geometric Spatial Assessment by Domain for Control and Experimental Gender Groups

Spatial Domain	**Con Male Pre (SD)**	**Con Male Post (SD)**	**Con Male Gain**	**Con Female Pre (SD)**	**Con Female Post (SD)**	**Con Female Gain**	**Exp Male Pre (SD)**	**Exp Male Post (SD)**	**Exp Male Gain**	**Exp Female Pre (SD)**	**Exp Female Post (SD)**	**Exp Female Gain**
Periodic Patterns	53.7 (22.7)	59.3 (28.7)	5.6	48.4 (26.6)	62.1 (24.0)	13.7*	47.7 (25.1)	49.2 (24.4)	1.6	47.1 (26.1)	43.8 (18.8)	-3.3
Geometric Spatial Visual.	43.5 (30.7)	54.6 (31.8)	11.1	49.2 (33.2)	60.5 (34.6)	11.3*	45.3 (24.8)	43.4 (28.3)	-2.0	39.2 (29.6)	46.3 (27.6)	7.1
Cardinal Directions	48.2 (21.8)	47.2 (27.2)	-0.9	45.2 (19.8)	45.2 (26.9)	0.0	41.4 (22.4)	40.2 (23.0)	-1.2	35.0 (20.2)	45.8 (25.7)	10.8*
Spatial Projection	43.5 (22.6)	42.6 (29.3)	-0.9	40.0 (24.2)	44.2 (27.6)	4.2	35.6 (21.7)	39.5 (21.3)	3.9	36.7 (25.8)	40.4 (22.1)	3.8

*$p < 0.01$

While the interaction effect between gender and time was not significant for either the control or experimental groups, one cannot help but notice the similarity in the plots shown in Figure 1 for both control and experimental groups where girls began with lower GSA scores and ended with higher scores than the boys.

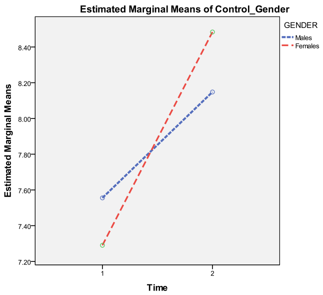

Figure1A: GSA control pre and post mean scores by gender

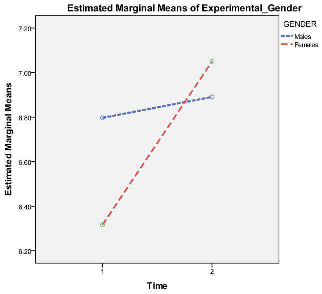

Figure1B: GSA experimental pre and post mean scores by gender

PSVT-Rot Results

The PSVT-Rot pre/post tests were given to 70 control and 111 experimental students. A RMANOVA revealed a significant increase in the mean values from pre to post for both control and experimental groups on overall test scores. Significant increases were also achieved by all gender groups except for experimental males (Table 7). These results indicate that *mental rotation* abilities are increased as a result of learning about Earth/Space science dealing with lunar phases no matter the curriculum or the instructional approach.

Table 7: Percent Scores on PSVT-Rot for Control and Experimental Groups

	n	Mean Pre % Correct (SD)	Mean Post % Correct (SD)	% Gain Score	*F*	*p*-value	Partial η^2
Control All	70	43.7 (20.2)	49.5 (21.6)	5.8	10.8	0.002*	0.135
Exp. All	111	35.6 (17.4)	40.1 (20.3)	4.5	7.035	0.009*	0.060
Control Males	35	45.9 (22.8)	52.9 (23.4)	7.0	6.26	0.017*	0.156
Exp. Males	61	38.4 (17.1)	42.9 (22.4)	4.5	3.04	0.086	0.048
Control Females	35	41.6 (17.1)	46.1 (19.3)	4.5	4.47	0.042*	0.116
Exp. Females	50	32.2 (17.2)	36.7(17.0)	4.5	4.53	0.038*	0.085

*$p < 0.05$

Conclusion

The authors claimed that one must have well-developed spatial skills in order to understand astronomical phenomena having to do with the Moon and its phases. Students could come to the classroom already equipped with strong spatial reasoning, ready to understand complicated Earth/Space phenomena; *or* students will begin to develop the necessary spatial ways of thinking as they make sense of the patterns, geometries, and motions.

As we compared control and experimental groups' LPCI learning outcomes, we found the experimental group made significant gains on the periodicity of the Moon's orbit and phases. The authors attribute these gains to their five-weeks of lunar observations since students had the opportunity to notice patterns and lunar orbital direction. Control females also made significant gains with direction of the Moon's orbit, and both control males and females made significant gains on domain E (*phase and Sun/Earth/Moon positions*). This was not surprising since domain E was emphasized during instruction through worksheets, simulations, and modeling.

In analyzing the GSA results, other interesting features emerged. Only experimental females made significant gains from pre to post in the area of *cardinal directions*. The integrated STEM curriculum emphasized documentation of the Moon's position in terms of cardinal directions. Like the experimental group, only control females made significant GSA gains; however, theirs were on *periodic patterns* and *geometric spatial visualization*. The emphasis on Sun/Earth/Moon configurations for various phases could explain the *geometric spatial visualization* development.

The PSVT-Rot showed all groups (except experimental males) achieving small but significant gains from pre to post. This assessment tested students' mental rotation ability, which we claimed was linked to *geometric spatial visualization* and *spatial projection*. A correlation test was run on the post assessments to see how well the PSVT-Rot correlated to the GSA and the LPCI, and how well the LPCI correlated to the GSA. Table 8 displays significant correlations between these assessments with every group except for the control males with PSVT-Rot versus LPCI. This supports our original claim regarding the connection between students' spatial reasoning and lunar-related understanding.

Table 8: Correlations Between Post-LPCI, GSA, and PSVT-Rot Results by Group

	LPCI vs. GSA		**PSVT-Rot vs. GSA**		**PSVT-Rot vs. LPCI**	
	r	***p*-val**	***r***	***p*-val**	***r***	***p*-val**
Control All	0.543	0.000*	0.511	0.000*	0.431	0.000*
Control Males	0.437	0.024*	0.409	0.042*	0.305	0.075
Control Females	0.63	0.000*	0.6	0.000*	0.593	0.000*
Exp. All	0.315	0.000*	0.462	0.000*	0.403	0.000*
Exp. Males	0.285	0.024*	0.495	0.000*	0.421	0.001*
Exp. Females	0.367	0.005*	0.413	0.004*	0.36	0.014*

Significance

This study is unique because it is the first quasi-experimental study that examines students' spatial reasoning as they participate in Earth/Space units. This study also extended previous research that examined the role gender plays in the development of spatial reasoning. Similar to Wilhelm's (2009) previous study, females scored lower and ended higher on three of four spatial domains (for both control and experimental groups). As noted earlier, brain developmental differences between gender groups during these preteen years could explain these results.

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