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The Effect of the Project Lead the Way Program on Students' Spatial Visualization Skills (Evaluation)

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Miss Elyse Hill, University of Guelph

I am a first year PhD student with current interests in control and estimation theory and pedagogy research. I hope to obtain a faculty position in mechanical engineering post-PhD and combine my interests into a new field of research.

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Abstract

Higher education is focused on finding the best ways to increase retention of engineering students. One of the best practices includes the student's ability to think and assess things with spatial reasoning. A four year study at the University of Maryland, Baltimore County (UMBC) showed that students who had completed a pre-engineering program in high school, Project Lead the Way (PLTW), scored significantly higher on the Purdue Spatial Visualization Rotations Test (PSVT:R) exam. As a result of this, a partnership was formed between the university and two high schools, each teaching a different pre-engineering class. This study was designed to assess how students dual enrolled in the pre-engineering and math courses performed on the PSVT:R compared to their peers who were enrolled solely in their concurrent math classes (calculus and geometry).

The assessment revealed that there was no significant difference between male and female student scores for those dual enrolled within the pre-engineering curriculum and math classes. This was not true for those students only enrolled in the math classes. In those cases, the male students consistently outperformed their female counterparts. Further analysis also demonstrated that female students in both pre-engineering classes scored significantly higher than their non-affiliated counterparts. The male students in one of the two math courses also outscored their non-affiliated counterparts. These results demonstrate that students in the pre-engineering programs have more developed spatial reasoning skills, better positioning them to be successful in higher education.

Introduction

Spatial visualization, a known cognitive skill, supports engineering student's abilities to mentally manipulate and assess two and three-dimensional figures. This skill is essential for their later classes as literature has shown the benefits of engineering students having strong spatial reasoning abilities [1,2,3.]

Pre-college Engineering programs are working hard to provide students the opportunity to investigate future STEM careers. Several of these programs have successfully motivated students into engineering careers leading to higher enrollments and retention of college engineering graduates. Project Lead the Way (PLTW), a pre-engineering program, has become one the well-known national programs providing students possibilities in the engineering and science fields. [4,5]

Project Lead the Way (PLTW) is an engineering curriculum that teaches students in K-12 engineering fundamentals including developing problem-solving abilities, critical thinking and key professional skills starting in kindergarten and continuing through high school.[4] Through the high school engineering pathway, students are introduced in their first core classes to essential engineering concepts that include the engineering design process, design tooling and analysis.

Since 2004, Maryland State Department of Education (MSDE) has adopted PLTW as one of their career and technology completer programs. PLTW engineering is established into more than 2200 of their schools to include elementary through high school. As university affiliated partner, 30% of the engineering student population either took a PLTW class or completed the career pathway.

Two core classes in the PLTW curriculum and pedagogy, Introduction to Engineering Design (IED) and Principles of Engineering (POE), provide heavy instruction, unintentionally, on spatial reasoning skills through activities such as 3D modeling and sketching and extensive real-world problem-based learning.[6]

In 2014, as a result of a NSF ENGAGE grant and research,[1,2,3] the College of Engineering and IT (COEIT) at UMBC established a class for students to improve their spatial abilities. This course specifically focused on chemical, computer and mechanical engineers. Native incoming freshman were asked to take the Purdue Visualization Exam, Rotations (PVST-R) prior to beginning their first semester. Students who performed below a 70% were recommended to enroll in Engineering Science 100, Spatial Visualization. Students were not required to take the exam or the class.

In examination of four years of students scores from UMBC, N=785, it was found that the PLTW graduate students performed significantly higher than non-programmed students $p<.005$.

This study examines the effect of the pre-engineering program, Project Lead the Way, on student's spatial visualization abilities in high school.

Framework and Literature Review

Spatial reasoning is a term used to describe an ability to visually perceive and conceptualize objects and spaces. This occurs, for example, "when an individual tries to perceive and copy an object or a shape and establish what it would look like if rotated by a certain angle."[7]

As higher education continues to seek the best practices to increase student recruitment and retention in engineering, spatial visualization has become an important intervention of study. Research exists asserting that those with better spatial reasoning ability do better in science, technology, engineering, and mathematics (STEM) related fields. [7, 8, 9] Conversely, poor performance of spatial visualization tasks has shown to affect self-efficacy on students leading to failure and even leaving the field.[9] Research on this ability has found that it improves through training even leading to closing the gender gap. [2,7,8,9] As such, efforts have been made to include the instruction of spatial reasoning in classes prior to college-entry to increase students' STEM achievement.

Various effective spatial training strategies exists on how to develop students abilities. One recommendation suggested that spatial training would provide the greatest benefit if pre-training or concurrent training existed with introductory STEM courses.[8] This training would yield the greatest impact if scheduled over an extended period of time.

Although spatial ability has been shown to affect STEM achievement in higher education, research on the influence of k-12 students is still developing. In relation to this study, few connections have been drawn on how high school pre-engineering programs develop these skills. More specifically, limited research evaluation on PLTW's impact on student spatial skills was found. Findings in Brudigam & Crawford's study, using only post-assessment, indicated that the engineering course had a positive impact upon the students' spatial reasoning.[6]

Purpose of the Study

The purpose of this study was to evaluate a pre-engineering program, Project Lead the Way (PLTW) courses, such as Principles of Engineering (POE) or Introduction to Engineering Design (IED), having an impact on spatial reasoning. More specifically the following questions were explored:

- Is there difference in performance in the Purdue Spatial Visualization Test (PSVT-R) between PLTW and non-PLTW students?
- Is there a significant difference in performance in the PSVT-R between male and female students both PLTW and non-PLTW?
- Is there a difference between the effect of PLTW course (POE and IED) on students' performance in the PSVT-R?

Methodology

To gain a deeper perspective of the causality of PLTW effect on student's spatial visualization skills, PLTW courses, Introduction to Engineering Design (IED) and Principles of Engineering (POE) were evaluated. Additionally, associated mathematic courses with both affiliate and non-affiliate students participated in the study to provide comparative analysis of PLTW vs. Non-PLTW students.

Two master teachers from the PLTW program agreed to participate in the study. Each of them brought over 10 years of experience teaching in the program. Additionally, each of the teachers identified colleagues in their math departments that administered the exam to their students. One of these schools was located in New York, POE, where the other is in Maryland, IED.

The Introduction to Engineering Design class and Principles of Engineering class are normally introduced in the freshman or sophomore classes of high school. The Introduction to engineering design class offered at the Maryland high school is executed as a 5-month semester-based class. The Principles of Engineering class is offered as 10-month class. All classes administered the exams during the middle of the fall term due to limitations in scheduling availability.

Participants

Participants in this study included high school students ranging from the ages of 14-17. Consent forms were sent to student homes authorizing permission for participation in the study. Students were given the choice to opt-out of participation in the study. To maintain anonymity, unidentifiable codes were used and given to each of the participants.

Students in the POE course were in their sophomore year and had previously taken IED. The IED students were high school freshmen taking their first pre-engineering class.

Instruments:

The Purdue Spatial Visualization Test (PSVT-R) is a validated tool using thirty questions to assesses how well one can visualize the rotation of three-dimensional objects. The test is often used as a predictor of spatial reasoning ability.[9] Traditionally the PVST:R is administered as a pre and post assessment tool, in this study the assessment was administered as point in time evaluation due to limitations and restrictions with the scheduling in the high schools. Future work that expands on these results will employ the more traditional pre and post assessment mechanics.

For PLTW students, PLTW Learning Management system (LMS), Canvas, was used to administer the survey. Non-PLTW in equivalent math courses took the assessment via Qualtrics, an online survey tool. The test was administered by their high school teachers during class time. Students were given 25 minutes to complete the exam. Additional demographic questions were asked at the end of assessment that included: gender, age, grade level, math class, and ethnicity.

Data Analysis

Analysis procedures included the Shapiro-Wilk test of normality, one-way Analysis of Variance (ANOVA), and t-test for independence. The Shapiro-Wilk test was applied to test if the data was normally distributed, since the sample sizes were small. A one-way ANOVA was used to test the mean difference between the performance of the males and females in the groups. Two-sample t-test was used to compare the means between the POE and IED groups and the PLTW versus non-PLTW groups.

Results

Below in Table 1a and 1b describes the demographics of the sampled population including PLTW and Non-PLTW students. Around 95% of the POE students previously had IED. IED students have no record of taking a PLTW course.

Table 1a: PSVT-R Demographics PLTW Students

PSVT-R Pre-Test Demographics				
	POE		IED	
Gender	Male	Female	Male	Female
Participant Amount (%)	48 (84.2)	9 (15.7)	16 (69.6)	7 (30.4)
Total	57		23	

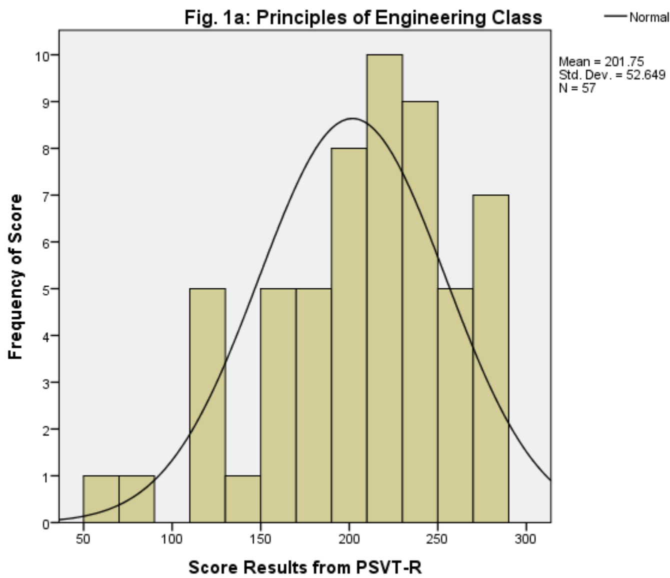
Table 1b: PSVT-R Demographics Math Students

PSVT-R Pre-Test Demographics				
	Geometry		Calculus	
Gender	Male	Female	Male	Female
Participant Amount (%)	31 (64.6)	17 (35.4)	29 (52.7)	26 (47.2)
Total	48		55	

Results from the PSVT-R for all classes are listed in Table 2 and are displayed graphically in Figures 1a and 1b. Using the Shapiro-Wilk test, PSVT-R scores were assessed for normality and homogeneity of variance. Assessing scores from IED and the geometry class, a normal distribution was shown for the entire class population including both female and male genders. However, the POE class data was not normally distributed. Variant results were revealed in the different populations for the Calculus class (Table 3). To determine significance, parametric and non-parametric test were utilized.

Table 2: Distribution of Results from PSVT-R for POE, IED, Geometry, and Calculus Classes

PSVT-R Distribution of Scores		
POE		IED
Student Amount	Score Range	Student Amount
2	≤ 100	3
20	$101 - 199$	9
35	$200 - 300$	11
Calculus		Geometry
Student Amount	Score Range	Student Amount
20	≤ 100	9
21	$101 - 199$	26
14	$200 - 300$	13



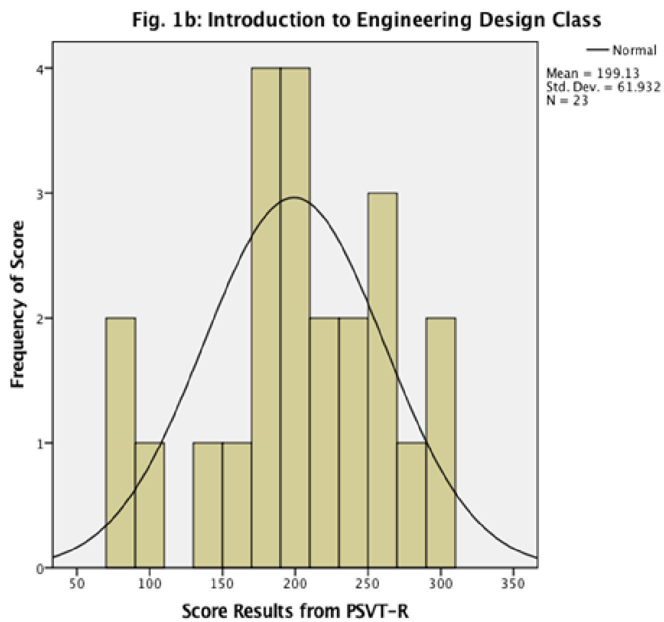


Figure 1: Score distribution of PSVT-R scores Figure 1a: Principles of Engineering & Figure 1b Introduction to Engineering Design

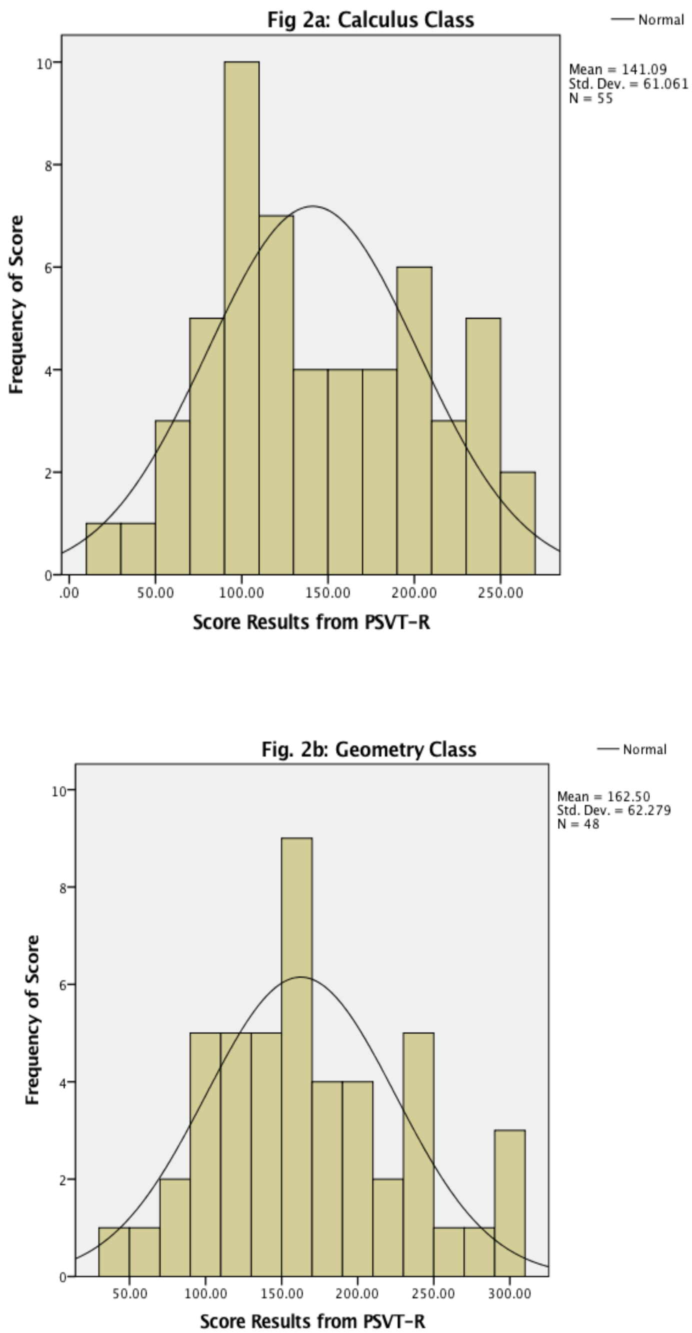


Figure 2: Score Distribution of PSVT-R scores Figure 2a: Calculus Class & Figure 2b:Geometry

Table 3: Results of Test of Normality for PLTW and Math Students

Tests for Normality				
	POE	IED	Calculus	Geometry
Group	Sig. Value*			
Entire Class	0.013	0.468	0.086	0.284
Males	0.012	0.807	0.022	0.730
Females	0.019	0.151	0.996	0.895

*p<.05

A one-way ANOVA analysis was performed comparing IED, Geometry, and Calculus class performance data between male and female students. A nonparametric independent sample test was performed on the POE data. The resulting p-values of the tests are displayed in Table 4:

Table 4: Significance Values Males v. Females for all Classes

Reported Significance Values	
Class	p-value (Sig)
POE	0.242
IED	0.270
Calculus	0.041
Geometry	0.004

*p<.05

No statistical significance difference between females and males was shown in the PLTW population for both IED and POE (p=0.270,p=0.242). However, Calculus and Geometry classes both showed clear gaps between the men and women. Female mean score values in both the math classes were significantly lower than their male counterparts. Mean values from each of the populations are shown in Table 5 and Figure 2.

Table 5: Means and Standard Deviations of Males and Females in All Classes

Means ± Standard Deviations of Scores				
	POE	IED	Calculus	Geometry
Females	181.11±46.218	177.14±71.348	123.46±50.35	128.82±43.72
Males	205.63±53.312	208.75±57.14	156.90±66.18	180.97±63.74
Total	201.75±52.549	199.13±61.93	141.09±61.06	162.5±62.28

An independent t-test presented no significant difference between the POE and IED classes; p=0.394. A small delta between the groups was calculated, Δ M= 2.62, with the POE class performing higher than the IED class on PSVT-R.

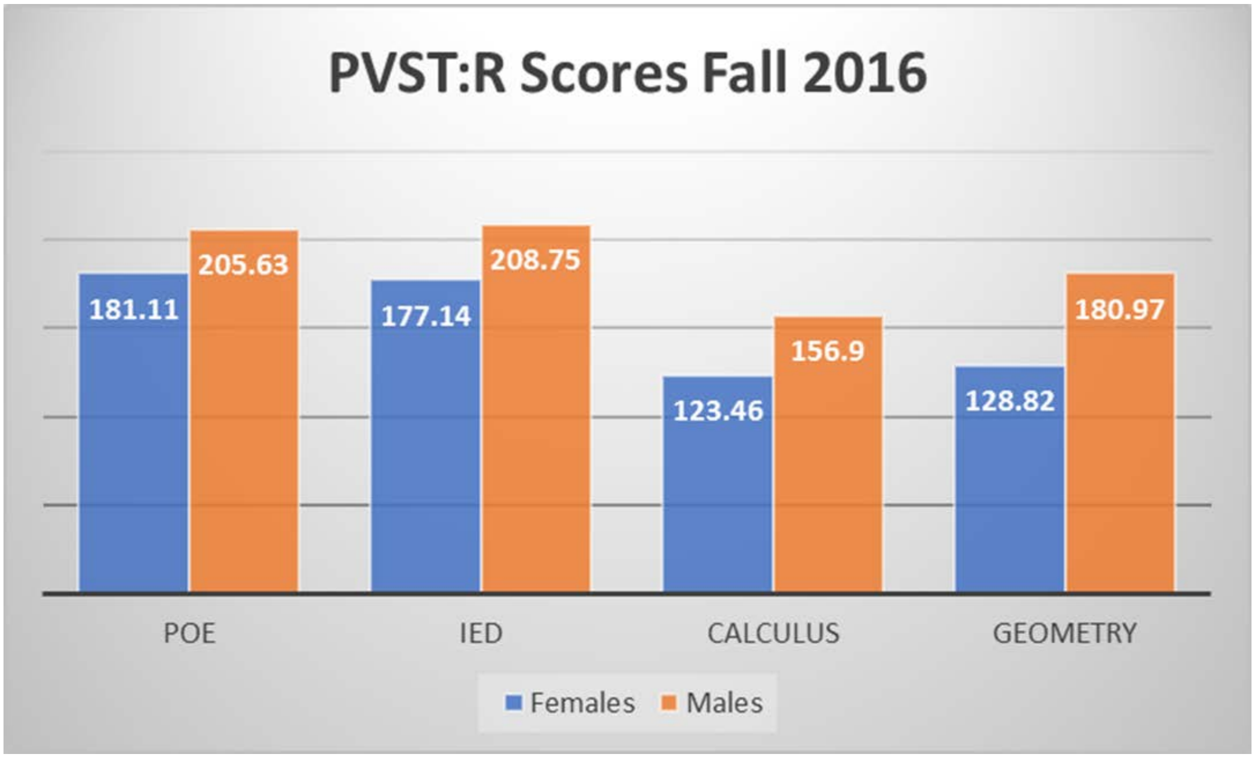


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Figure 2: Mean values of PLTW classes

In comparing the calculus and geometry students' scores, no significant difference was shown; p=0.082. The mean difference between the two groups was small, Δ = 21.41, with the geometry class performing higher than the calculus class on PSVT-R.

Collectively, the pre-engineering classes compared to both mathematical classes, revealed no significance difference. However, separately, each pre-engineering class significantly scored higher compared to the simultaneous math class. In table 6, IED and the female population performed considerably better in the exam than their counterparts who were non-PLTW. Males in IED or geometry performed the same.

While there is technically no significant difference between the performance of females, the p-value is small enough to be considered significant (p=0.053). The mean value of females in IED was 177.1 points, whereas in the geometry they performed lower with a mean value of 128.8 points.

Table 6: Significance Values by Class: Introduction to Engineering Design vs. Geometry

Reported Significance Values	
Group	p-value (Sig)
Entire Class	0.023
Males	0.150
Females	0.053

*p<.05

Table 7: Significance Values by Class: Principles of Engineering vs. Calculus

Reported Significance Values	
Group	p-value (Sig)
Entire Class	0.000
Males	0.001
Females	0.005

*p<.05, *p<.005

Table 7 also shows significance in the performance on the PSVT-R between POE and calculus. All three populations of PLTW students in POE scored significantly higher than their counterparts in calculus. Comparing these results to the class mean values shown in Table 5, students in the PLTW POE class have greater spatial abilities than their non-programed affiliated counterparts.

Conclusions and Future Work

This paper presents a preliminary evaluation of the impact PLTW pre-engineering program has on the spatial visualization abilities on high school students.

Analysis illustrated that both PLTW classes outperformed students enrolled only in concurrent math classes on the PSVT-R. When comparing both populations, a statistically significant difference was observed between the performance of male and female students on the PSVT-R, indicating that both genders of PLTW students significantly outperformed their non-programmed affiliated counterparts. There was one case where this result did not hold true, the IED and Geometry male students displayed no obvious difference in their scores.

Pre-engineering students showed no statistical difference between genders while their non-programmed counterparts displayed a notable difference between male and female performance. These findings suggest that PLTW curriculum has a positive effect on the spatial reasoning ability of students, especially regarding gender. Data from this study suggest that dual enrollment in PLTW and math leads to increased spatial visualization abilities as compared to solely being enrolled in math courses. This is especially true for female students who show no marked difference with dual enrollment but underperform their male counterparts when only enrolled in math classes. This supports previous studies that just looked solely at IED and AP Geometry.[6]

There are several recommendations to further enhance the analysis of this study. One such recommendation would be to increase the sample population size since there is often a low ratio of male to female students in these classes. As research shows, collecting more data from additional high schools would yield more accurate results, creating a more representative and diverse female population to analyze.[10]

One final recommendation would be to add in a post-test analysis, which is not included in this study. Time and scheduling limitations at the high schools did not allow for the intended post-test to occur in a manner that was consistent with the initial assessment. Analysis of a post-test would reveal if PLTW or math curriculums improve spatial reasoning capabilities as the school year proceeds. It could also reveal if gender differences are eliminated among the courses and their populations. The improvement by both curriculums could then be compared to determine which course has the most impact on spatial reasoning ability.

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