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Non-Traditional Spatial Ability Training Methods and their Effect on CAD Proficiency

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Abstract

Research has demonstrated that spatial abilities, such as mental rotation, object cutting, and folding, are critical for success in STEM disciplines, where computer-aided design (CAD) software is significant to tasks requiring spatial proficiency. This study examines the impact of non-traditional spatial ability training on CAD proficiency among second-year engineering students in an entry-level design course. Using the Spatial Vis app, twelve participants of the intervention group were assigned modules that included hand sketches and rotations. Pre- and post-training spatial abilities were assessed using the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R), and CAD proficiency was measured through Certified SolidWorks Associate (CSWA) scores.

Data was collected through a survey on academic performance, personal experience, and hobbies to determine if there is any significant impact on PSVT:R and CSWA scores. Results indicate a significant positive effect of the training app on CAD proficiency, though changes in spatial abilities were inconclusive due to a small sample size. Video games also showed to have a relationship to pre-PSVT:R scores when played two to five hours weekly. Gender, sports, major, and academic experiences showed limited correlation with spatial or CAD outcomes. This study highlights the potential of non-traditional spatial training to enhance CAD skills and better prepare students for STEM careers.

Keywords: spatial visualization, spatial ability, computer-aided design

Motivation and Background

Spatial ability is a general term defined as the natural ability to visualize with no prior training. Metrics can include cutting, folding, and rotating objects in one's head. Spatial visualization is a sub-component of spatial abilities and can be defined as the mental ability to manipulate, transform, and analyze two and three-dimensional objects [1], [2], [3], [4]. This skill is essential for students in engineering as conveying an idea through hand sketching or CAD modeling is a required skill [5], [6]. It has also been shown to play a significant role in students' performance in STEM-related tasks and has displayed a positive correlation to CAD modeling [7], [8], [9], [10].

Previous work has shown that males generally have better spatial visualization than females. However, with intervention, women have been proven to close the gap between their male counterparts [11], [12]. A study conducted at Michigan Technological University using average PSVT:R scores from 1996 through 2009 shows that both males and females' spatial abilities have increased, but females are increasing faster. This trend could contribute to a more inclusive and gender-balanced STEM field [12], [13].

Spatial visualization is a teachable skill that can be improved over time through personal experience. Playing with Legos, participating in certain sports, strong mathematical skills and hands-on activities such as a shop class have all been shown to develop spatial abilities [2], [13], [14], [15]. New interests such as 3-dimensional (3D) video games, virtual reality (VR), and augmented reality (AR) have been investigated for their impact on spatial abilities as technology has become more accessible. Research suggests that playing Tetris and action games can help enhance spatial abilities. However, the impact of AR and VR on spatial abilities is under-evaluated [16], [17], [18].

There are various methods to improve spatial abilities and more will continue to arise over time. For the context of this study, they were broken down into two categories: traditional and non-traditional approaches to spatial abilities training. A traditional approach is defined by the authors as an activity that uses an analog approach, such as hand sketching, building, and origami, all of which have been found to improve spatial abilities [7], [19], [20]. The authors define non-traditional approaches as tasks that are done virtually or require an electronic device for interaction, like app-based spatial ability training, AR, Tetris, or the 3D video games previously mentioned. A training app, Spatial Vis, uses hand sketches and rotations in a game-like fashion to enhance spatial abilities, and a statistically significant increase in spatial abilities was observed when implemented in a study conducted at Stevens Institute of Technology [7].

Spatial abilities have been shown to play a role in predicting academic success in engineering education. Such skills have also been associated with science and mathematics performance. Given that engineering is mathematically intensive, this can be used as a metric to predict students' performance. However, evaluating spatial abilities and mathematics course grades can better predict performance in undergraduate engineering design courses than math grades alone [21], [22]. Additionally, students with higher spatial abilities have been shown to graduate from engineering programs at higher rates than students with lower spatial abilities. Although this may lead to a more precise prediction of student success, other factors, such as motivation and persistence, influence academic outcomes. Previous work has found a correlation between academic performance and motivation, proving that prediction of success is a multifaceted problem [22], [23].

To examine and quantify students' spatial abilities, there are several tests that have been developed, such as The Mental Cutting Test (MCT), Mental Rotation, and The Revised Minnesota Paper Form Board Test [24], [25], [26], [27]. One of the most used is The Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R). The PSVT:R has proven to be a reliable measure of spatial abilities through its longevity and has been the top choice for many conducting research in engineering education [13], [21].

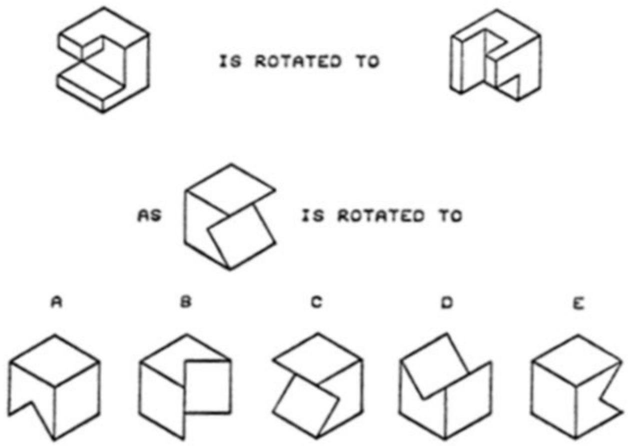

Figure 1: An example question from the PSVT:R

The PSVT:R consists of 30 multiple-choice questions, like Figure 1, where students are asked to rotate an object as indicated by another object's rotation. All questions have five options and must be completed in twenty minutes or less. The grading scale ranges from zero to 9.99, with 9.99 being a perfect score [28].

Methodology

This section will outline the methodology for the study, including participants, course curriculum, tests and test conditions, and the evaluation metrics for the study.

Participants

The study was conducted in a second-year, introductory engineering design course. The participants were predominantly male, accounting for approximately 74% of the sample size, as shown in Table 1.

Table 1: Participants by gender

Gender	**Number of Participants**
Prefer not to say	4
Females	11
Males	42
Sample Size	**57**

The course is a graduation requirement for all engineering students, resulting in 8 different STEM majors participating in the study. This allows the opportunity to analyze spatial abilities from various perspectives. However, a large percentage of the participants are mechanical engineers (ME), as it is one of the larger departments at the university. A breakdown of participants by major is shown in Table 2.

Table 2: Participants by major

Major	Number of Students
Environmental Engineering	1
Computer Science	1
Industrial Engineering	2
Engineering Physics	3
Civil Engineering	3
Electrical Engineering	7
Computer Engineering	13
Mechanical Engineering	27
Total	**57**

Curriculum

Due to the rising importance of 3D modeling skills, a significant portion of the class is dedicated to CAD modeling on SolidWorks to prepare students for the CSWA exam. The course also requires students to construct a bridge out of manila folders using a template provided. Both CAD modeling and construction-based projects have shown positive correlations to spatial abilities. Therefore, there is expected to be an increase in spatial abilities among all participants [2], [7], [8], [13]. The primary research question is:

"How do nontraditional training methods affect CAD proficiency?".

Due to the use of CAD being part of the course, it will not be analyzed as a training method but as a test to assess outputs to find correlations between modeling and spatial abilities. Two students in the sample had already been CSWA certified and attempted the Certified SolidWorks Professional (CSWP). However, these students may be out of the scope of the study when analyzing CAD proficiency, thus omitting their data when analyzing impacts on CSWA scores.

Baseline Tests

The PSVT:R was provided by eGrove Education in the form of a Canvas quiz to quantify spatial abilities. Also, a survey with various questions was given via Canvas to assess personal experience as it relates to spatial abilities [29].

The participants were asked to rate their perceived CAD modeling abilities ranging from one to seven. This data was analyzed to determine if there is any correlation between a student's perceived ability and the outcome of the CSWA. There were also questions relating to academic success and experience, including cumulative GPA and whether the student participated in any experience in engineering-based courses in high school. While the experience question was represented by binary, in the GPA question, students were asked to select one of five possible responses. One is less than 2.0, two being 2.0-2.5, three being 3.5-3.0, four being 3.0-3.5, and five being 3.5-4.0. With these two metrics, a conclusion could be drawn on whether academic experiences influence 3D modeling proficiency.

The next group of questions that were analyzed involved hands-on experience. Students were asked if they had any engineering-related work experience or certifications and how often they used hand tools on a scale of one to seven with one being never, four being around once a month and seven being every day. The idea is to analyze these metrics to determine if prior hands-on experience contributed to a higher PSVT:R score and in turn higher CSWA score which is the main indicator in this study for CAD proficiency.

The next series of questions the students answered were based on hobbies and childhood experiences. Participants were asked if they played any sports and for how long. The question included five response options: One being never, two being less than two years, three being three to four years, four being five to seven years and 5 being more than seven years in a sport. This was an interesting question to analyze due to a wide range of responses. Similarly, whether students played video games also brought a wide range of responses. Students were asked to select from the following five responses: one means they do not play video games, two means less than two hours, three is two to five hours, four is five to seven hours and five is more than seven hours. The next question inquired whether the students played with constructible toys, such as Legos and Lincoln Logs, as a child. The final question on this part of the survey asked participants if they enjoyed hands-on or do-it-yourself (DIY) projects. The overwhelming majority claimed to have played with constructible toys and enjoyed DIY projects. Hands-on activities have proven to enhance spatial abilities; however, with much of the sample claiming to have done or enjoy doing hands-on activities, it may be more difficult to draw meaningful conclusions [2], [13], [14], [15].

<u>Intervention vs Control Conditions</u>

Students were offered the opportunity to complete modules in a non-traditional spatial ability training app called Spatial Vis. The ten modules included an introduction, 2D rotations about one and two axes, iso and ortho cubes (2D representations of 3D objects), 2D to 3D transformations, patterns, and assemblies. The application's objective is to improve spatial abilities and better prepare students for STEM careers. Figure 2 below gives an example problem of a 2D rotation from the Spatial Vis app. The user is expected to take the shape shown by the solid line and rotate it to the indicated direction at the 90 and -90 degrees.

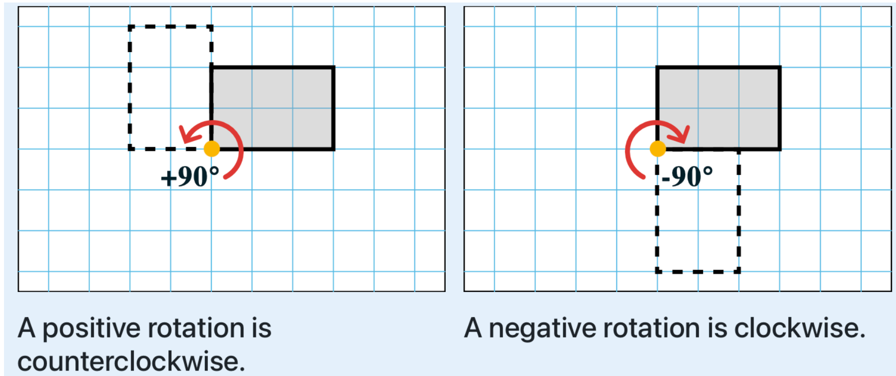

Figure 2: An example problem of a 2D rotation from the Spatial Vis app

Each module had tasks that were to be completed and were graded out of three stars. The hints and answers can be requested but will negatively affect the number of stars received for a given task. The tasks are graded on persistence, meaning submissions will be accepted with no penalty if a hint or a solution is not given, and then the Spatial Vis app will automatically grade them [29]. The intervention consisted of twelve participants who chose to use the Spatial Vis app to enhance their spatial abilities in hopes of improving class performance, while the remaining forty-five students served as a control, deciding not to partake in any intervention.

<u>Post Tests and Evaluation</u>

The data received from the CSWA scores will give insight into the effectiveness of a non-traditional training method in enhancing students' CAD proficiency. This will be cross-referenced with other qualitative and quantitative data to reveal any trends with respect to PSVT:R score or spatial ability and 3D modeling capability. After completion of the CSWA, both the control and the intervention groups will be assigned a post-PSVT:R on Canvas. The data from the post-PSVT:R will be compared to the pre-PSVT:R to determine if the Spatial Vis app impacted their spatial abilities. A visual representation of how the study was performed is shown in Figure 3.

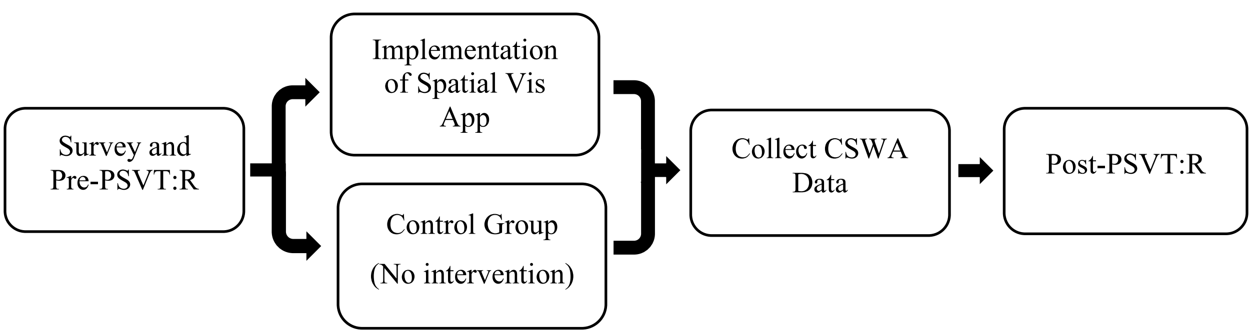

Figure 3: Flowchart of the study

Results

Gender Differences

Literature has shown that males are generally better at spatial visualization than females. To test this, the pre-PSVT:R was split into males versus other genders. When testing for normality, it was males were normally distributed while the scores for all other genders were not.

Due to the differences in normality, a rank sum comparison of participants who had completed both the pre and post-PSVT:R was performed using a Kruskal-Wallis Test to compare medians. On the pre-PSVT:R, males outperformed all other genders by an average of .84 points, which is nearly 10% of the points that could be awarded. On the post-test, males scored lower on average than their pre-test and were outperformed by the remaining genders. This is reflected in the pre to post-PSVT:R differences, where males scored an average of .14 points less than they did on the initial test, while females and prefer not to say increased by an average of almost one point.

Table 3: Kruskal-Wallis median comparison results and pre and post-PSVT:R score analysis by gender

Pre-PSVT:R	Male	Non-male
Average	7.83	6.99
Observations	30	11
p-value	0.211	
Post-PSVT:R	Male	Non-male
Average	7.68	7.93
Observations	30	11
p-value	0.401	
Pre/Post difference	Male	Non-male
Average	-0.14	0.94
Observations	30	11
p-value	0.353	

It is important to note that this only includes the data from the participants that completed both the pre- and post-PSVT:R surveys. Some of the following results may show all 57 participants that completed just the pre-PSVT:R. This is done to improve granularity where possible, especially when referring to the students' incoming spatial ability in comparison to their performance with computer-aided design.

Table 3 shows the difference in mean values, with the pre-PSVT:R and the difference in pre- to post-test scores being the most pronounced. However, a p-value greater than 0.05 was calculated for all three categories, indicating that the difference in medians was not statistically significant. This implies that the difference in spatial abilities between males and non-males is negligible as it pertains to the pre- and post-PSVT:R results and the difference from pre to post-tests.

PSVT:R Scores by Major

Although the sample is diverse, due to the course requirement for ME's, almost half of the class declared their major to be mechanical engineering. This was more than double the second most abundant major, computer engineering (CE). As shown in Figure 4, the sample includes five majors with fewer than five participants, making it difficult to draw meaningful conclusions by comparing averages for each major. For this reason, it was decided to analyze MEs versus the remaining sample.

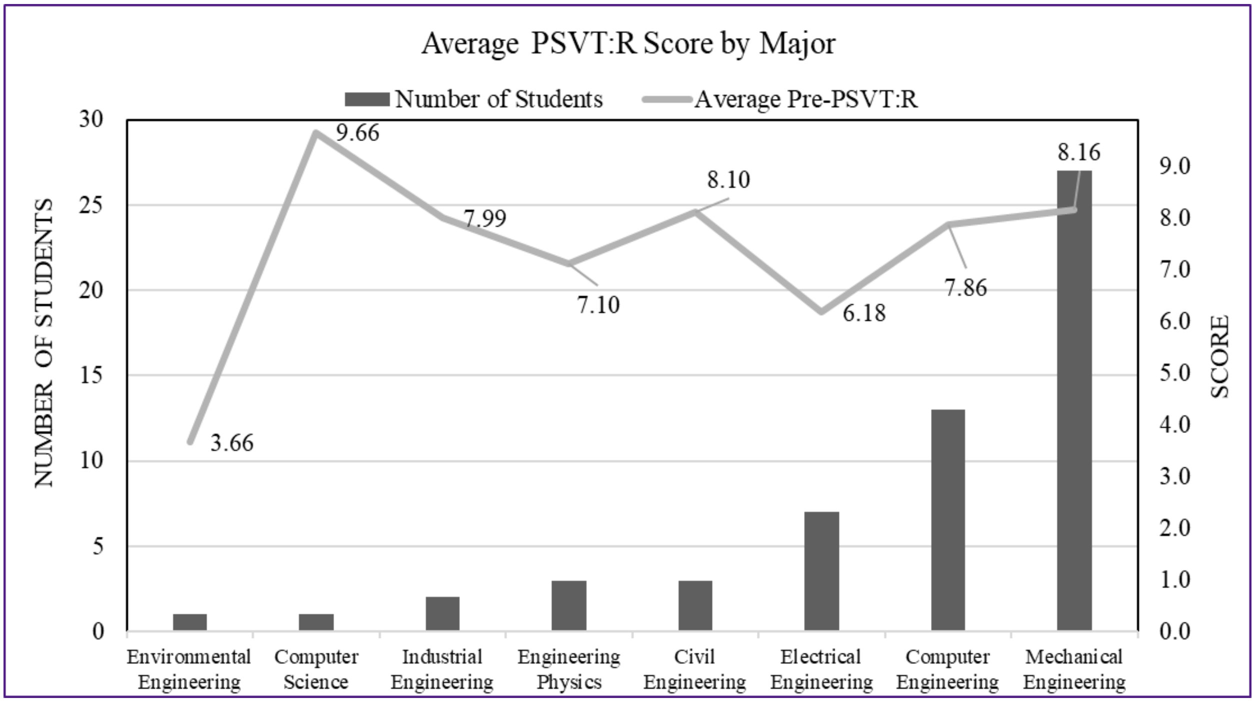

Figure 4: Number of participants and average of all pre-PSVT:R scores by major

As shown in Figure 4, MEs had the highest average when compared to all other majors with more than one participant. A Kruskal-Wallis test was used to compare the mean pre-PSVT:R score of ME's versus all other majors. The resulting p-value was greater than .05, implying that no evidence exists that ME's have better spatial abilities than those of the other participating majors grouped together. Table 4 shows the results of the analysis.

Table 4: Analysis of all pre-PSVT:R scores with respect to major

	Mechanical Engineers	All Other Majors
Average	8.16	7.35
Observations	27	30
p-value	0.076	

PSVT:R Scores vs. CAD Performance

When plotting pre-PSVT:R scores against CSWA scores, a slight trend exists. However, an R^2 value of .2715 was insufficient to conclude whether the two are related. Figure 5 visualizes the relationship between pre-PSVT:R and CSWA scores.

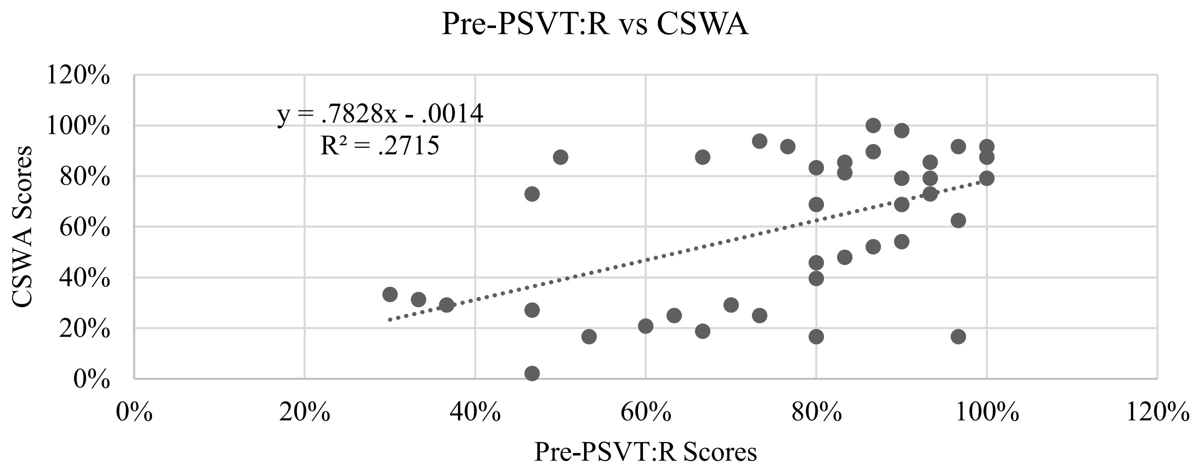

Figure 5: Relationship between normalized pre-PSVT:R and CSWA scores

When analyzing the correlation between spatial abilities and CAD proficiency, the PSVT:R and CSWA scores were approximately normal, and a t-test was performed to provide additional insight into the relationship. Table 5 shows that when comparing pre-PSVT:R and CSWA scores in a two-tailed t-test declares the result insignificant by a small margin. Although there is a positive correlation when plotting CSWA versus Pre-PSVT:R scores, there was not enough evidence to declare them significant. As for the post-PSVT:R vs CSWA, there was a p-value higher than 0.05 for the two-tailed t-test. Due to both p-values being greater than 0.05, the differences in means were deemed insignificant.

Table 5: Results to determine significance of normalized mean differences between pre and post-PSVT:R and CSWA scores

	Pre-PSVT:R	**CSWA**
Average	7.602	8.785
Observations	41	41
p-Value	0.051	
t-stat	2.021	
	Post-PSVT:R	**CSWA**
Average	7.748	8.785
Observations	41	41
p-Value	0.208	
t-stat	2.021	

Next, the students' self-reported, perceived CAD ability was compared to pre-PSVT:R and CSWA scores to determine if there was a relationship. Table 6 shows that the differences in means are vastly different. This observation is reinforced by a p-value significantly lower than 0.05 for both pre-PSVT:R and CSWA scores versus a participant's perceived ability. This implies that there is no relationship between performance on the pre-PSVT:R or CSWA and the student's perception of their CAD abilities.

Table 6: Perceived CAD ability vs CSWA and pre-PSVT:R scores

	Pre-PSVT:R	**CAD Ability**
Average	7.602	4.843
Observations	41	41
p-Value	1.226E-08	
t-stat	2.021	
	CSWA	**CAD Ability**
Average	8.785	4.843
Observations	41	41
p-Value	1.167E-06	
t-stat	2.021	

A Kruskal-Wallis test was used to determine if engineering courses taken in high school influence spatial abilities and CAD proficiency. When analyzing both pre-PSVT:R and CSWA scores, the data was split into those who participated in engineering courses in high school vs. those who did not. When accounting for all participants who completed the pre-PSVT:R, CSWA, and the survey, the p-value was greater than 0.05 for both comparisons, as shown in Table 7. This indicates that there is no evidence to support the claim that students who take engineering courses in high school have greater spatial abilities and are more proficient at CAD.

Table 7: Statistical analysis to determine if engineering courses in high school correlate to an increase in pre-PSVT:R and CSWA scores

Pre-PSVT:R		
	Engineering Courses	No Engineering
Average	7.86	7.24
Observations	34	19
p-Value	0.349	
CSWA		
	Engineering Courses	No Engineering
Average	139	134
Observations	34	14
p-Value	0.853	

Categorical Data

Due to the non-normality of the data, a piecewise comparison was made using a Kruskal-Wallis test. Participants were categorized based on their responses to the survey question and compared sequentially to determine if any meaningful conclusions could be made. The participants who took the CSWP were not included in any analysis regarding the CSWA.

Research suggests that there is no correlation between GPA and spatial abilities. To test this, the students were divided into four groups according to their responses to the question of the GPA survey. The averages for pre-PSVT:R scores among GPA groups were relatively close. The findings were predictable, with the lowest p-value being 0.409, suggesting that there is no significant difference in pre-PSVT:R scores when dividing the participants by GPA. There was a noticeable leap from group four to group five when comparing GPA to average CSWA scores, where the average CSWA score increased by over thirty points, or 12.5% percentage points. Although the difference in averages was interesting, the piecewise comparison resulted in a p-value of .10729; therefore, the difference is deemed insignificant. Results can be found in Table 8.

Table 8: GPA versus pre-PSVT:R and CSWA scores

Pre-PSVT:R vs GPA				
Group	**2**	**3**	**4**	**5**
GPA	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0
Observations	6	13	19	18
Average	7.71	7.94	7.50	7.79
Comparison	2→3	3→4	4→5	-
p-Value	0.965	0.409	0.514	-
CSWA vs GPA				
Observations	6	13	19	18
Average	101	126.7	129.7	162.5
Comparison	2→3	3→4	4→5	2→5
p-Value	0.539	0.730	0.107	0.230

The studies that have explored the relationship between video games and spatial abilities revealed that certain types of games can contribute to improved spatial visualization. To examine this further, the amount of time spent a week playing video games was recorded and compared to pre-PSVT:R and CSWA scores. When analyzing the data, it was noticed that the participants who played for two to five hours had the highest average score for both tests, while the ones who did not play video games had a significantly lower score. A piecewise comparison out of sequence to examine the difference between the means shown in Table 9. It was found that those who play video games for two to five hours weekly are more likely to score higher on the PSVT: R than people who do not play. This is exhibited by p-value of 0.009 when comparing the 2 groups. Alternatively, when comparing the CSWA scores, the lowest p-value found was .31151, implying that playing video games does not increase CAD proficiency.

Table 9: Video games versus pre-PSVT:R and CSWA scores

Pre-PSVT:R vs Video Games					
Group	**1**	**2**	**3**	**4**	**5**
Video Games	Do Not Play	<2 Hours	2-5 Hours	6-8 Hours	8+ Hours
Observations	11	6	15	13	11
Average	6.63	8.16	8.48	7.28	8.39
Comparison	1→2	2→3	3→4	4→5	1→3
p-Value	0.097	0.613	0.097	0.087	0.009
CSWA vs Video Games					
Observations	11	6	15	13	9
Average	118.6	121.7	152.3	141.2	138.3
Comparison	1→2	2→3	3→4	4→5	1→3
p-Value	0.651	0.312	0.800	0.841	0.402

A statistical analysis was done to determine if there is a correlation between sports and spatial abilities or CAD proficiency as shown in Table 10. The averages among all the groups were similar for pre-PSVT:R and CSWA scores with all averages being within ten percentage points of each other. The piecewise comparisons revealed that there is no relationship between sports, spatial abilities, and CAD proficiency with the lowest p-value of 0.350 occurring when comparing groups who played for five to seven years and seven or more years.

Table 10: Sports versus pre-PSVT:R and CSWA scores

Pre-PSVT:R vs Sports					
Group	**1**	**2**	**3**	**4**	**5**
	Never Played	<2 years	3-4 years	5-7 years	7+ years
Observations	12	13	6	9	16
Average	7.96	7.74	6.99	7.92	7.68
Comparison	1→2	2→3	3→4	4→5	1→3
p-Value	1	0.460	0.814	0.497	0.531
CSWA vs Sports					
Observations	10	13	6	9	16
Average	145.5	129.6	144.2	157.2	123.8
Comparison	1→2	2→3	3→4	4→5	1→5
p-Value	0.556	0.726	0.814	0.350	0.150

Intervention

Of the fifty-seven people who participated in the study, twelve consented to complete modules in the Spatial Vis app via a canvas survey. Out of those twelve, only seven completed both the pre- and post-PSVT:R. This reduction in sample size makes it difficult to analyze and draw any meaningful conclusions from the data. The difference between pre- and post-PSVT:R scores were calculated for the control and intervention group and then compared using a Kruskal-Wallis test. Surprisingly, the intervention group's average score difference was negative, meaning that most of the participants who did use Spatial Vis performed worse on the post-PSVT:R. Table 11 displays the calculated p-value as 0.00039, meaning there is a significant difference in the difference of PSVT:R scores in favor of the control group. The same test was performed to analyze the relationship between the Spatial Vis app and CSWA scores with an interesting result. When comparing all twelve of the intervention group's CSWA scores to the control group, it was found that there is a statistically significant difference in scores between the two groups. Participants who utilized Spatial Vis averaged 173.3 on the CSWA, whereas the control averaged 125.4, thus yielding a p-value of 0.0191. This indicates that students who use Spatial Vis are more likely to score higher on the CSWA than students who do not utilize the platform.

Table 11: Intervention versus control data for all assignments

Pre-PSVT:R		
	Intervention	Control
Observations	12	45
Average	8.16	7.62
p-Value	0.61768	
Post-PSVT:R		
Observations	7	34
Average	7.52	7.80
p-Value	0.70311	
Change in PSVT:R Score		
Observations	7	34
Average	-1.23	0.43
p-Value	.00039	
CSWA		
Observations	12	45
Average	173.3	125.4
p-Value	0.0191	

Excluded Metrics

Some metrics from the survey were excluded due to one-sided and subjective responses. The fact that most participants only spoke one language, therefore that question was removed from consideration. A similar situation occurred with questions involving hand tool usage, DIY projects, work experience, and construction toys with most of the samples stating similar responses. The last metric that was excluded was whether a participant had any relevant certifications. This was irrelevant as there was an element of subjectivity, and most participants did not have any certifications. The ones that did have certifications had them in skills that were out of the study's scope.

Discussion

This study examined various metrics ranging from academics, hobbies, and personal experience against spatial abilities (PSVT:R) and CAD proficiency (CSWA) to determine if any correlations existed between them. There was also a statistical analysis of the improvement of PSVT:R and average CSWA scores to investigate the effect of a non-traditional spatial abilities training using the app Spatial Vis. When comparing pre- and post-PSVT:R scores and score differences from the pre and post-test by gender, it was determined that there was not a significant difference between them. This goes against what previous literature has stated, however, the sample consists of mostly males, thus making it difficult to draw conclusions.

A similar situation occurred when analyzing pre-PSVT:R scores by major. The sample was mostly ME's. However, MEs scored almost ten percentage points higher on the pre-PSVT:R than the other majors. Although the difference in scores was deemed insignificant, the p-value was 0.076. If a confidence interval of 90% was used, there would be a statistically significant difference and could potentially warrant further investigation into the relationship between major and spatial abilities.

The analysis to follow was the relationship between pre-PSVT:R and CSWA scores. There is a noticeable trend showing an increase in CSWA scores with an increase in pre-PSVT:R scores. After normalizing the data, performing linear regression, and performing a t-test, it was determined that there was no significant difference between average normalized pre-PSVT:R and CSWA scores. This indicates that there is a relationship between PSVT:R and CSWA scores due to the mean values being close enough to conclude that there is a trend. In simpler terms, a higher score on the PSVT:R can result in a higher CSWA score.

Scores from the pre-PSVT:R and CSWA were compared to the participant's perceived CAD ability. The scales were normalized, resulting in vastly different averages and a t-test was performed. To be expected, the p-values for both pre-PSVT:R and CSWA scores were extremely low. This implies that there is no relationship between perceived CAD ability and the performance on the PSVT:R and CSWA. This is not surprising, as most students have never been tested on their CAD ability and thus have no objective way to determine CAD proficiency.

Next, engineering courses taken at the high school level were investigated to analyze the impact on spatial abilities and CSWA scores. It was determined that there is no evidence to support the claim that engineering courses in high school had any effect on spatial abilities or CSWA scores. This comes as a surprise, as engineering-based courses may consist of activities such as 3D modeling, hand sketching, and construction-based projects. All of which have been shown to impact spatial abilities. More research into what tasks were assigned in the course may give insight into how the courses do or do not affect spatial abilities or CAD proficiency.

Although research suggests that there is no correlation, there was a noticeable increase in CSWA score averages when comparing participants from the 2.0-2.5 and 3.5-4.0 GPA groups. After evaluating categorical data, it was found that there is no correlation between GPA and spatial abilities or CAD proficiency. The same can be said for sports and their relation to CAD and spatial abilities. The averages of pre-PSVT:R and CSWA scores for the group that played sports for three to five years were ten percentage points lower than participants who claimed to have never played a sport. This does not coincide with previous research; however, an entire study could be dedicated to sports and its impact on spatial abilities and CAD proficiency.

Previous research has shown that action games can enhance spatial abilities, however little research has been done on the duration in which games are played and how that may affect spatial abilities. When video games were analyzed, it was found that there is a significant difference between people who play two to five hours and people who do not play at all. This could be an indication that playing video games in moderation does increase spatial abilities. However, the students that played video games for more than 5 hours a week showed a decrease in spatial skills.

When analyzing the Spatial Vis app, it was found that the participants who used the training app are more likely to score higher on the CSWA than those who did not. As previously mentioned, the Spatial Vis app contains hand sketches and rotations, which have been proven to increase spatial abilities. However, the post-PSVT:R and the difference between pre- and post-PSVT:R scores show that the difference in averages is insignificant. Although a correlation between spatial abilities and Spatial Vis was not identified, the topic warrants more research into the effect of non-traditional training methods on PSVT:R and CSWA scores.

Limitations

Many tests that were performed were insignificant, most likely due to limited participation in the intervention. Many students chose not to participate in the intervention, leaving a small group of twelve to be analyzed. Of the twelve participants who did consent to intervention, only seven completed the post-PSVT:R. For this reason, it is believed if a larger number of students participated in the intervention and completed the study, that there would have been a statistically significant difference in participants who utilized the Spatial Vis app versus those who did not.

Another possible reason for insignificant results is that the average difference between pre- and post-PSVTR was negative for those who took part in the intervention. It is believed that students were less motivated to complete the study due to the post-PSVT:R being at the end of the semester. Students were most likely fatigued and were less willing to complete an assignment that was not graded or incentivized.

There could have been some potential bias in allowing the students to voluntarily participate in the intervention rather than assigning a group at random. It is possible that students who took part in the intervention are more motivated and perform better because they are more persistent. Additionally, if a student fell behind during the semester, they may have applied more effort to increase their chances of performing better in the remainder of the class. Although these possibilities could have potentially affected the results of the study, there is no objective way to analyze this without additional examination. Although bias may be present, the study was exploratory and aims to influence other future studies

Conclusion

This study examined the impact of non-traditional spatial ability training on CAD proficiency among second-year engineering students in an entry-level design course. Pre- and post-training spatial abilities were assessed using the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R), and CAD proficiency was measured through Certified SolidWorks Associate (CSWA) scores. Data was collected through a survey on academic performance, personal experience, and hobbies to determine if there is any significant impact on PSVT:R and CSWA scores.

The study has concluded that video games have a statistically significant impact on spatial abilities when played in moderation, although it showed to have no effect on CAD ability. The same cannot be said for academic performance, previous engineering-related courses, and playing sports. There was also a relationship between pre-PSVT:R scores and CSWA scores, even though Figure 5 shows only a moderate correlation. The Spatial Vis app has been shown to enhance CAD modeling proficiency in a meaningful way, however, due to the sample size and incomplete surveys, it is difficult to conclude whether the intervention is impactful. Although previous work reports that the Spatial Vis app-based spatial ability training is impactful and has the potential to increase spatial abilities, additional research into the topic would aid in reinforcing these findings. Additional studies investigating spatial abilities training could lead to further findings, enhancing academic performance and assisting students in their journey through engineering.

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