The Role of Spatial-Visual Skills in a Project-Based Engineering Design Course

THE ROLE OF SPATIAL-VISUAL SKILLS IN A PROJECT-BASED ENGINEERING DESIGN COURSE

Although spatial-visual skills have been found to be a strong predictor of success in and aptitude for engineering practice and related technical fields, comparatively little research has been conducted on its function in engineering coursework, particularly engineering design. The purpose of this study was to examine the role of spatial-visual skills in a core undergraduate mechanical engineering design course requiring each student to design and build a robot to accomplish a complex task in a competition. The researchers hypothesized that students with higher spatial abilities would produce more complex designs (although complexity is not necessarily desirable); as spatial abilities are associated with understanding how physical objects can be assembled, students with high spatial ability may be better able to understand and design intricate integrated systems. The Purdue Spatial Visualization test was administered to 137 students (79 male, 58 female) at the start of the course, and these results were analyzed with self-assessments of each student's experience in tasks associated with spatial skills (such as creating origami models, sketching, and creating CAD models), the complexity of their produced robot, and their robots' performance in the culminating class competition.

For all students, the correlation between spatial test score and the percentage of moving components in a design was found to approach significance with a negative correlation. Spatial reasoning was positively correlated with origami experience for male students in the study. Spatial test scores did not seem to be linked to competition performance. However, although not statistically significant, the total number of components and number of moving components for a mechanism were negatively correlated with students' scores in seeding rounds of the competition. These results suggest that strong spatial-visual abilities may not directly relate to design outcomes and that simplicity rather than complexity may be desirable for competition performance.

Introduction

Spatial-visual skills incorporate a person's ability to visualize and mentally transform or manipulate an object in space. For example, engineers may utilize spatial-visual skills when designing a part; they must understand features of the part from multiple perspectives (e.g. top or isometric projection) while integrating the part among a variety of other components in an assembly. Although much research has been devoted to how spatial reasoning may be improved through instruction[1,2] comparatively little research has been conducted to understand the role theses skills play in engineering design.

The purpose of this study was to study the role of spatial-visual design within the context of an undergraduate engineering design course. In particular, the researchers aimed to explore possible connections between spatial-visual skill and ability in engineering tasks associated with spatial reasoning such as sketching, physical prototyping, and creating CAD models. Design complexity was also analyzed with respect to spatial-visual skills. Although not necessarily valued over simplicity[3], complexity was hypothesized to be a characteristic of designs produced by students with high spatial-visual abilities. Because spatial ability is associated with understanding how objects can be assembled and move with respect to other subcomponents, students with higher spatial ability may be better able to understand such integrated systems and may therefore be more likely to design them.

Spatial-visual skills of undergraduate mechanical engineering students in a requisite design and manufacturing course at MIT were assessed using the Purdue Spatial Visualization Test: Visualizations of Views (PSVT:V)[4]. The test was administered at the start of the semester along with a survey in which student self-reported their abilities in the following tasks, which are associated with spatial-visual skills: sketching, using CAD software, building physical prototypes, and making origami figures. Robots that students developed for the course were examined with several metrics for complexity including the number of components composing their design and the percentage of moving components. Finally, performance in the culminating competition was analyzed to discover trends between performance and spatial-visual ability. The purpose of this study was to address the research question:

"How might spatial-visual ability affect systems design and design outcomes?"

Results from this work may aid educators of engineering design courses to understand the impact graphics courses may have on student design work.

Background

Spatial-Visual Skills

Spatial-visual skills are a measure of a person's dexterity in performing mental transformations of objects. According to developmental psychologist Howard Gardner, who includes visual-spatial intelligence as an intelligence in his multiple intelligences theory, visual-spatial reasoning consists of several distinct skills including mental recall and transformation of objects in a physical domain[5].

Educational psychology literature defines spatial-visual skills in multiple ways and uses several closely related terms to refer to spatial-visual abilities and skill (for further reference, refer to [2]). In this paper, spatial-visual skills will be used interchangeably with spatial reasoning and refers to ones ability to mentally manipulate an object in space through one or multiple steps[1].

Spatial-visual skills evolve from an understanding of space that emerges during infancy, typically categorized under the sensorimotor stage of cognitive development[6]. Children at this stage, who are usually under the age of two, develop navigation skills and learn to appreciate and predict the trajectory of moving objects. Once the child develops into the preoperational stage, usually from ages 2 to 7, the child is able to actively manipulate objects, which is known as *operative knowledge*. *Operative knowledge* may be contrasted with *figurative knowledge* where the former describes one's ability to imagine an object from different perspectives by mentally transforming the object while the latter describes one's ability to simply remember how an object appears.

It is believed that operative knowledge and spatial reasoning can be fostered through activities that require hand-eye coordination such as playing 3D video games or using physical manipulatives such as tangible construction kits[1,2]. In a longitudinal study of students identified as intellectually talented during the 7th grade, Shea et al. found that students with strong spatial skills relative to verbal ability in the 7th grade were likely to pursue engineering and mathematics fields as their undergraduate major and full-time occupation[7]. They characterized signs of spatial giftedness as including strong grades in science, math, and vocational courses and hobbies in building and tinkering. Prior work supports the idea that children with exceptional spatial skills may gravitate towards engineering and scientific disciplines.

Spatial reasoning is believed to be an important skill for engineers when performing tasks such as designing mechanisms and assemblies and creating digital models of parts using CAD programs[1]. In interviews conducted with ten engineering instructors and industry professionals, Hsi et al. found that their interviewees learned spatial reasoning in different ways. Some cited natural ability or hands-on experience as sources for gaining spatial skills. They also believed that spatial reasoning was rarely used in isolation, and although they were unsure of how spatial reasoning specifically applies to engineering practice, they nonetheless thought spatial reasoning skills were important. These interviews suggests that further research into the role that spatial skills plays in engineering practice may be needed to understand its impact on design outcomes.

Spatial Reasoning Assessment

A variety of tests are used to assess spatial-visual skills including the Mental Cutting Test[8], the Differential Aptitude Test[9], and the Purdue Spatial Visualization Test[10]. These assessments test a person's spatial ability in a variety of ways such as having the test-taker determine the cross-sectional view of an object, determine how a three-dimensional object would appear when a two-dimensional image is folded, and imagine how an object would appear when viewed from a particular perspective.

For this study, the Purdue Spatial Visualization Test: Visualization of Views (PSVT:V) was utilized because it has been used to assess spatial-visual skills in a previous study on spatial ability of engineers[11]. This test involves perspective-taking, which requires test-takers to image how an object would appear when seen from a perspective other than their own. An example of a test question on the PSVT:V is shown in Figure 1. Test-takers imagine how the three-dimensional object, located in the center of the cube, would appear from the perspective indicated by the black dot on the edge of the cube. In the example shown, the black dot is in the top left corner, and the answer is (c).

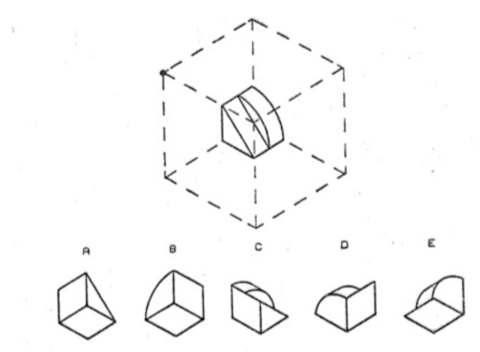


Figure 1: Sample PSVT:V question[10]

Gender Differences with Spatial-Visual Skills
A significant amount of research is dedicated to gender differences found on spatial-visualization assessments. Generally, males tend to significantly outperform females on spatial reasoning tests[12,13]. Differences have been attributed to a multitude of factors including biological, social and cultural, and educational factors and are believed to contribute to the fact that males outnumber females in science and mathematics fields. For example, brain lateralization studies have found that males have a greater degree of lateralization, meaning that the left side of the brain that is primarily responsible for visual-spatial operations is dominant[14]. Others believe that spatial ability may be a recessive trait carried on the x-chromosome[15]. Test taking conditions may also contribute to differences in scores; in a study conducted by Goldstein, no significant differences were found between male and female scores on spatial reasoning tests for untimed tests although differences were noted when the test was timed[16]. Despite initial differences, it has been shown that spatial reasoning can improve through instruction[1,2].

Spatial-Visual Skills and Engineering Design
As summarized in the literature review, much research has been dedicated to the predictive power of spatial-visual skills in determining major and occupation and gender differences in spatial-visual ability. Although spatial reasoning is often associated with engineering tasks that require visualization skills such as sketching or creating mechanical assemblies, little research has been conducted to explore the role spatial reasoning plays in engineering design. This study adds to the literature to better understand how spatial-reasoning may affect design outcomes.

Methodology

Testbed
Students tested in this study were enrolled in the undergraduate mechanical engineering course Design and Manufacturing I (2.007) at MIT. The course is typically taken by sophomore students who have taken introductory statics and dynamics courses. Before enrolling in 2.007, students are required to have completed a two-week long course offered directly before 2.007 that introduces students to various mechanical engineering design tools and machinery such as Computer-Aided Design (CAD), mills, and lathes. Besides this short course, students are not required nor expected to have any previous background in mechanical design.

Over the course of a semester, each student in 2.007 builds their own remote-controlled robot using stock materials such as aluminum extrusions, plastic rods, and lumber. All students are given the same set of materials and have access to the same set of tools in the machine shop. At the end of the semester, students use their robots to compete in a competition where they aim to score points by accomplishing various tasks on a contest table. Certain tasks are worth more points than others, so students must develop a design for their robot that incorporates their strategy for the competition. During the competition, students compete against each other in sixty-second rounds, and the rounds continue until there is one overall winner.

The course is structured such that students design separate components of their robot before a final integration process. Each mechanism of the robot is called a *module*, and each robot has a *Most Critical Module* (MCM), or a component that performs the task the student believes is the most important to their robot's success. Students spend the first half of the semester developing their MCM and use the remainder of their time to integrate their MCM with the rest of their design. In this paper, mechanism will be used interchangeably with MCM as the MCMs of students' robots were analyzed in this study.

For most students, 2.007 is their first chance to work in a machine shop and build a complete mechanical system from scratch. Several visualization techniques are taught in the course including basic drafting, solid modeling, and prototyping. Students in 2.007 were a valuable resource for testing whether students' visual-spatial abilities at the beginning of the course affected the design of their mechanisms.

Spatial-Visual Assessment and Skill Set Survey

The PSVT:V test was administered to 137 mechanical engineering undergraduate students (79 male, 58 female) during the second week of the course before any formal visualization techniques were taught. Along with the test, students were administered a short survey in which they indicated their skill level in several tasks associated with spatial reasoning: sketching, using CAD software, building physical prototypes, and making origami figures (Figure 2). Skill level was scored on a Likert scale from one to five with one indicating no experience, three indicating basic experience, and five indicating substantial experience.

Gender : M F

Please rate your skill level based on the following scale:

(1 = no experience, 3 = basic experience, 5 = substantial experience)

	1	2	3	4	5
Sketching Skills					
Using CAD Programs (SolidWorks, AutoCAD, etc.)					
Building physical prototypes (woodwork, foam-core, etc.)					
Making origami figures					

Figure 2: Skill set survey

Responses for each category were totaled for each student for a cumulative survey score indicating their experience level in all four tasks. The purpose of the survey was to compare each student's PSVT:V score with their self-reported skill levels to examine any possible correlations between experiences in certain activities and spatial ability. Students were given ten minutes to complete both the survey and the PSVT:V test of thirty multiple-choice questions. Students were not expected to finish the exam as eighteen minutes are usually given for the test. Course time constraints limited the amount of time available to administer the test during class.

Exam scores were calculated as the number of correct answers minus one quarter of the number of incorrect answers (of the questions answered) in order to minimize random guessing and avoid heavily penalizing for not completing the test. The scoring algorithm was used in a prior study on spatial-visual skills conducted by the MIT Man-Vehicle Laboratory[11]. With this scoring, the maximum possible score is 30.

Measuring Design Complexity

Students were required to design, build, and test their robot's Most Critical module (MCM) by the middle of the semester. Mechanisms of 34 randomly-selected students (19 males and 15 female) who had taken the PSVT:V were examined on several objective and subjective metrics for measuring complexity. Each MCM was photographed and analyzed in person to accurately account for all of their components.

Objective metrics hypothesized to indicate complexity were as follows: the total number of components composing the MCM, the percentage of components custom-made by students, the number of moving components, the percentage of moving components, degrees of freedom, and planar versus three-dimensional movement. These criteria were selected as measures of complexity with the assumption that an MCM with a larger number of components may require more thought and time, both in design and manufacturing, to complete. Furthermore, mechanisms with a larger number of degrees of freedom or ones that exhibit three-dimensional rather than planar movement may be more complex. Mechanisms that were constrained to planar movement were given a score of 1 while three-dimensional movement was given a score of 2. The number of components in an MCM did not include fasteners such as screws and rivets. Pre-made components such as gears and motors were included.

Custom-made components were components that students machined from stock material or modified from its original form. For example, although air cylinders and motors were counted in the total number of components, the parts were not included in the count for custom-made components since they were pre-made.

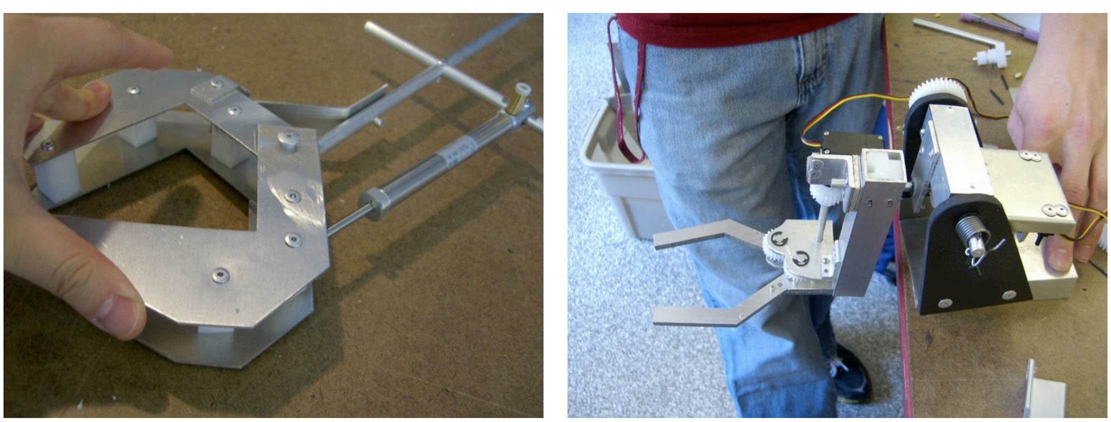
The number of moving components was determined to be the number of parts that rotated with respect to a stationary component or components of the MCM. Two examples of MCMs are shown in Figure 3. For the omni-directional wheels shown in Figure 2a, each plastic piece rotated with respect to the aluminum frame. As a result, the rotating plastic pieces were counted as moving components, leading to a total of 32 moving parts. For the crane shown in Figure 2b, all parts moved with respect to a stationary base, which is held by the student in the picture. All parts excluding the ones on the base were counted as moving, leading to a total of 38 moving parts.

(a) Omnidirectional wheels (32 moving parts) (b) Crane (38 moving parts)

Figure 3: Examples of MCMs with moving components

Two subjective criteria were used to judge the MCMs: originality and complexity. Both were judged on a scale from 1-5 with 5 being the highest score. Each MCM was judged by both the primary author and a lab instruction for the course. The averages of scores for each MCM was utilized in analysis.

An example of two claw mechanisms is shown in Figure 4. Many students in the course designed claws to pick up components on the contest table. As a result, most claws were given an average originality score of 3 unless there was a factor that made the MCM distinctive. Figure 4a exhibits a claw mechanism that utilizes an air cylinder to open and close the claw. It has one degree of freedom and was given an originality score of 2.5. Figure43b shows a claw mechanism that was designed with three different gear trains, allowing the claw to open and close, rotate side to side, and move vertically; this MCM was given a higher originality score of 3.5.



(a) Claw MCM 1 (b) Claw MCM 2

Figure 4: Two claw mechanisms

Complexity was defined as an overall impression of how intricate the mechanism was compared to the other MCMs analyzed in the study and was a combinatory score that took into account the total number of parts and degrees of freedom. Figure 3a was given a complexity score of 5 while Figure 4a was given a complexity score of 3.

Student Competition Performance
At the end of the semester, students entered their robots into a class competition. All students participated in seeding rounds before the competition in which they attempted to score as many points as they could. In seeding rounds, students did not compete directly against another robot. Points in the seeding rounds were used to determine brackets for the competition; highest scoring robots were paired against lowest scoring robots in initial brackets. Competition rounds consisted of two students competing against one other to score the most points in a sixty-second match.

Seeding score, seeding rank, competition score, and competition rank was recorded for all students that participated in the competition. Seeding scores and ranks may be significantly different than competition score and competition rank both because of inconsistency in performance but also because the dynamics of a competition matches can change when students are competing head-to-head. Some students specifically design their robots to interfere with an opponent rather than score points on the table, thus preventing their opponent's robot from scoring as many points as it may have been able to without interference.

Data Analysis
As the purpose of the study was to determine whether spatial-ability affected design complexity, Spearman correlations were used to compare PSVT:V scores with competition perforance and MCM metrics for complexity. Spearman correlation coefficients R_s can range from -1 and 1 with $-1 < R_s < 0$ indicating a negative correlation and $0 < R_s < 1$ indicating a positive correlation between two quantities. Statistically significant R_s values were determined for each given sample size for a significance level α: 0.05. Wilcoxon rank-sum tests were used to test for differences between males and females on the PSVT:V test, and double sided t-tests at a significance level of *p:* 0.05 were used to compare differences between groups of students.

Results

Spatial-reasoning test scores were analyzed and compared with MCM complexity criteria and competition performance to analyze emergent correlations. Significant differences between students of varying spatial ability are outlined in the sections below.

Spatial Test Results
On average, students completed 24 out of 30 questions on the PSVT:V test (SD: 6.3 questions) with test scores ranging from 0.75 to 30. Thirty-nine percent of all students completed all 30 questions, and five students received a perfect score (4 male, 1 female). Three students that answered less than ten questions on the exam were removed from the sample since the number of questions they completed was lower than two standard deviations below the mean. It was possible that these students did not have the full ten minutes for the test as a result of arriving

late for the experiment. Excluding these three students, a total of 134 students were tested (78 male and 56 female).

As shown in Table 1, students did not differ significantly in the average number of questions completed; however, a statistically significant difference was found between test scores of male and female students ($p<0.001$). Although both genders answered a similar number of questions, females answered a greater percent of questions incorrectly. These differences are consistent with prior work on gender differences in spatial reasoning[2].

Table 1: Number of questions answered and PSVT:V scores

Sample	**Average Number of Questions Completed (SD)**	**Test score (SD)**
All students (n: 134)	23.9 (6.3)	17.9 (8.0)
Females (n: 56)	22.7 (6.5)	15.3 (7.4)
Males (n: 78)	24.8 (6.0)	19.9 (7.5)

Survey Results and Spatial Test Scores
Students completed a self-evaluation survey on their experience sketching, using CAD software, building physical prototypes, and making origami figures. Experience was rated on a Likert scale from 1-5 where 5 indicated substantial experience. Skill set total represents a cumulative score for experience in all four skill-sets. Because three students did not complete the survey, a total of 131 surveys were used for analysis. As indicated in **Table 2,** students rated themselves slightly below average in all four categories, representing their belief that they have "basic experience" in each of these skills.

Table 2: Self-evaluation survey responses for experience in various tasks

	All Students (n: 131)	**Females (n: 54)**	**Males (n: 77)**
Skill Set	Average Rating (SD)	Average Rating (SD)	Average Rating (SD)
Sketching	2.8 (1.1)	2.8 (1.2)	2.8 (1.0)
Using CAD software	2.3 (1.2)	2.3 (1.2)	2.3 (1.2)
Building Physical Prototypes	2.8 (1.2)	2.7 (1.0)	2.9 (1.3)
Origami Skills	3.0 (1.3)	2.6 (1.3)	2.1 (1.2)
Skill Set Total	10.1 (3.4)	10.2 (3.5)	10.0 (3.3)
PSVT:V Score	17.9 (8.0)	15.3 (7.4)	19.9 (7.5)

Correlations between survey responses and spatial-test scores are shown in Table 3. A statistically significant positive correlation was found between experience with origami and PSVT:V scores for male students.

Table 3: Correlation between survey responses and PSVT:V test scores. Statistically significant correlations bolded.

	All Students (n: 131)	Females (n: 54)	Males (n: 77)
Skill Set	R_s	R_s	R_s
Sketching	-0.007	0.161	-0.155
Using CAD software	-0.035	-0.144	0.014
Building Physical Prototypes	-0.023	0.043	-0.137
Origami Skills	0.074	-0.043	**0.248**
Skill Set Total	0.017	-0.0349	0.0281

$R_s > 0.224$ is considered statistically significant at $\alpha = 0.05$ (two-tailed) for a sample size $n = 34$.

Mechanism Complexity and Spatial Test Scores

Thirty-four robots were randomly selected for analyzed for complexity using the aforementioned criteria. Nineteen of the robots were designed by male students. Most Critical Modules were analyzed for planar or three-dimensional motion where a score of 1 was given for planar motion and a score of 2 was given for three-dimensional motion. Originality and complexity were scored on a scale of 1-5 with five being the most original or complex. A summary of complexity data collected is shown in Table 4.

Table 4: Complexity data for 34 student robots

Complexity Metric	**Range**	**Average (SD)**
Number of components	3-64	21.6 (15.2)
Percentage of custom-made components	7.8-100%	67.4% (32.0%)
Number of moving components	0-58	12.0 (12.2)
Percentage of moving components	0-100%	55.6% (28.6%)
Degrees of freedom	1-3	1.4 (0.5)
Planar / 3D Motion	1-2	1.4 (0.05)
Originality	1-4.5	3.2 (0.9)
Complexity	1-5	3.1 (1.0)

Students with MCM complexity data were categorized into one of three groups: lower tier, or students who scored more than a standard deviation below average on the PSVT:V test; middle tier, or students who scored between one standard deviation below and one standard deviation above average; and upper tier, or students who scored above one standard deviation above average. Because a significant gender difference was found for the spatial reasoning assessment, students were divided into tiers based on gender; for example, female students were compared to the average female PSVT:V score while male students were compared to the average male PSVT:V score. The lower tier contains a total of 3 students while the middle tier and upper tier contain 19 and 12 students respectively.

There was limited data on the mechanisms of lower tier students; only data from three students was available for the lower tier, while the middle tier had 19 and the upper tier had 12. Eight percent of the mechanisms studied were of lower tier students, while 17% of the students who took the PSVT:V test were in the lower tier. As a result, students that scored in the lower tier on the PSVT:V were underrepresented. Students in the upper tier were overrepresented (34% of the MCM data set while they represented 20% of the entire class).

As displayed in Figure 5, students in the lower tier of spatial test scores had, on average, less components in their mechanisms than students in the middle of upper tier. Although students had a similar number of moving components, lower tier students had a higher percentage of moving components in their most critical modules. No differences between tiers of students were found to be significant except differences in PSVT:V score. However, when mechanism complexity was correlated with spatial test score, the percentage of moving components was found to be negatively correlated with test score (α: 0.059, R_s: -0.328).

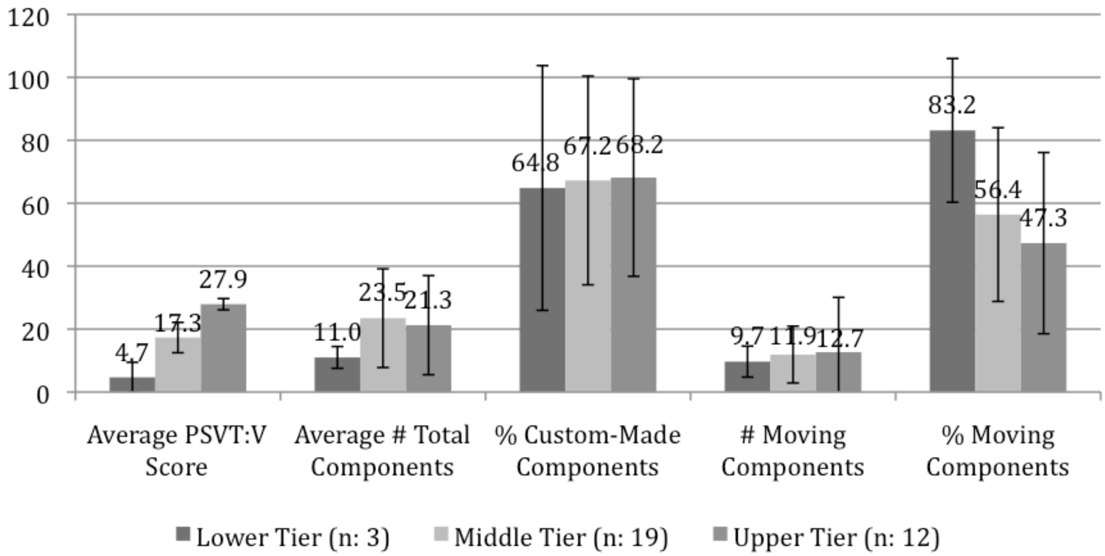


Figure 5: Mechanism component analysis by tier

Ratings for originality and complexity did not differ for students by tier as shown in Figure 6. Further, students who scored higher on the spatial-reasoning test were more likely to have mechanisms with greater degrees of freedom and which incorporated three-dimensional motion rather than planar motion.

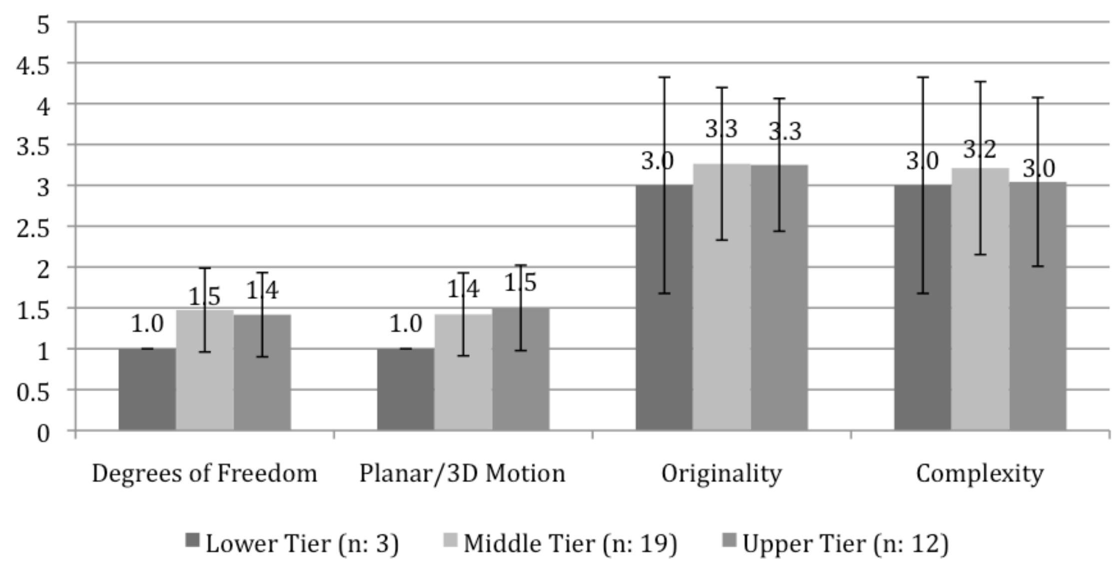


Figure 6: Degrees of freedom, planar vs. three-dimensional motion, originality, and complexity of mechanisms

Competition Performance and Spatial Test Scores
Not all students were able to compete in the competition for a variety of reasons such as having an incomplete robot or being unable to attend the competition. Eighty-nine of the 134 students who took the PSVT:V test competed in the competition.

During seeding rounds, students attempted to score as many points as possible on the competition table. Seeding round scores ranged from 0 to 9 points with an average score of 1.4 (SD:1.55). Seeding score and competition rank were positively correlated (R_s: 0.502, $\alpha < 1 \times 10^{-6}$), so for the sake of brevity, only analysis for seeding score will be discussed. Competition score was omitted since several students competed in multiple rounds, and scores were highly variable as a result of differences in strategy. For example, some robots were designed to interfere with others to prevent an opponent from scoring as many points as she may have been able to otherwise. In contrast, robots did not compete directly against each other in seeding rounds, enabling students to more accurately test their robot's ability to score points.

Spatial test scores were not found to correlate with seeding score (R_s: 0.0608, α: 0.5715); furthermore, survey responses were not found to correlate with seeding score (Table 5). Students in the lower, middle, and upper tier of spatial test scores did not differ in their performances in seeding or competition rounds.

Table 5: Correlations between survey responses and seeding score

Skill Set	**Correlation Coefficient R_s**
Sketching	0.0254
Using CAD software	0.0999
Building Physical Prototypes	0.0723
Origami Skills	0.0106
Total Skill Set	0.0803
Spatial Test Score	0.0608

For a sample size of n = 89, $R_s > 0.208$ is considered statistically significant at $\alpha = 0.05$ (two-tailed).

Twenty-eight of the thirty-four robots that were analyzed for complexity competed in the competition. Correlations between complexity metrics and seeding score are shown in Table 6.

Table 6: Correlation between seeding score and complexity metrics

	Correlation Coefficient *Rs*		
	All Students (n=28)	Male Students (n=17)	Female Students (n=11)
Spatial Test Score	-0.143	-0.149	0.387
Number of Components	-0.149	-0.284	-0.540
Percentage of Custom-Made Components	0.111	0.0903	0
Number of Moving Components	-0.269	-0.388	-0.361
Percentage of Moving Components	-0.135	-0.200	0.120
Degrees of Freedom	-0.135	-0.220	-0.0690
Planar/3D Motion	0.0277	-0.112	-0.463
Originality	0.223	-0.0547	0.307
Complexity	0.0172	-0.0301	0.213

For a sample size of n=28, $R_s > 0.375$ is considered statistically significant at $\alpha = 0.05$ (two-tailed).
For a sample size of n=17, $R_s > 0.488$ is considered statistically significant at $\alpha = 0.05$ (two-tailed).
For a sample size of n=17, $R_s > 0.618$ is considered statistically significant at $\alpha = 0.05$ (two-tailed).

Spatial-visual ability does not appear to directly impact a robots' performance in seeding rounds. Although no correlations are statistically significant, several approached significance. In particular, the number of moving components was negatively correlated with seeding score for all students (*p*: 0.1658) and for male students in particular (*p:* 0.1243). Furthermore, the number of components and three-dimensional motion appeared to be negatively correlated with spatial test score for female students (*p:* 0.0862 for number of components, *p:* 0.1076 for three-dimensional motion). These results suggest that simplicity rather than complexity may be more desirable for improved competition performance.

Discussion

Survey Results

The correlation between origami experience and PSVT:V scores was found to be statistically significant for male students (*p:* 0.030, *Rs*: 0.248). This result suggests that experience with origami may be linked to spatial-visual ability, although for female students, no statistically significant correlation was found. It may be possible that this difference may result from self-reporting skill level or because of a small sample size.

A possible limitation of the survey is that it asked students what their experience level was with particular tasks, which may or may not correlate with skill level. While the skill sets selected were chosen because they were believed to be relevant to spatial-visual thinking, it may be possible that other skills play a larger role; for example, sketching may rely more heavily on motor coordination, and prototyping may be more dependent on experience working in a machine shop. Since engineers draw on many different types of skills to perform these tasks, spatial-visual ability alone may not necessarily play a dominant role. This is consistent with interview responses with engineers where they believed spatial skills to be important but believed that they were rarely used in isolation[1].

Mechanism Complexity
The correlation between the percentage of moving components in an MCM and PSVT:V scores approached significance with a negative correlation (α: 0.059, *Rs*: -0.328). However, the number of components grew slightly with increasing spatial-test score while the number of moving components remained consistent. As a result, differences in the percentage of moving components are a result of an overall increase in the number of components for students with higher spatial-test scores.

Seeding Scores
Competition performance was found to be uncorrelated with spatial test scores or survey responses; as a result, it does not appear that spatial ability alone impacts students' competition rankings or scores. However, correlations between performance and design complexity metrics revealed that complexity may negatively impact competition performance. The number of total components, number of moving components, and complexity of motion (three-dimensional motion versus planar motion) were negatively correlated with seeding score. In other words, reducing complexity in the design of mechanical mechanisms appeared to be connected to improved competition performance.

Conclusions & Future Work

The analysis outlined in this paper characterizes several design outcomes of engineering students based on their spatial ability. Spatial-ability appeared to have little direct impact on design complexity, suggesting that other factors may more strongly impact mechanism design. Examples of factors that may influence design outcomes are sketching ability, skill working in a machine shop, and prior-experience with engineering design.

Correlations between design complexity criteria and competition performance indicated that complexity may negatively impact competition scores. This result suggests that simplicity rather than complexity may lead to better design outcomes.

Future work may more closely monitor spatial-ability over the course of the semester to determine whether participation in a mechanical design course may improve spatial-visual ability. Furthermore, a large sample size may help substantiate some of the trends noted in this preliminary study.

Acknowledgments

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