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Student Perceptions of Spatial Ability Importance in an Introductory Engineering Course

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Abstract

This complete research paper focuses on first-year students' spatial ability and their perceptions of its importance. While prior studies linked strong spatial ability training to improved academic performance, retention, and problem-solving in STEM, less attention was given to students' perceptions of its relevance to their chosen fields. This study employed a mixed methods approach, examining both measured spatial ability and student perceptions among students enrolled in the first-year introductory engineering course. A spatial ability test was administered alongside an open-ended survey question that asked students about the perceived importance of the spatial skill assessed by the test. Results indicated a significant variation in student spatial test scores across majors. Students who articulated the importance of spatial ability in their field tended to score higher than students who did not perceive any importance. Qualitative findings further revealed differing levels of understanding regarding the application and relevance of spatial skills. These results suggest a relationship between perception and performance, with implications for first-year curriculum design.

1. Introduction

Spatial ability is an umbrella term encompassing a variety of distinct spatial skills, including spatial visualization, such as mental rotation, mental transformation, and spatial relations, such as mental folding. Spatial ability is the cognitive capacity to mentally manipulate, transform, or rotate an image of a system, and comprehend its relation to other systems [1], [2]. In particular, spatial visualization refers to a person's ability to comprehend a system's space, location, and direction [3]. A system, in this case, is any area or object meant to be studied in an engineering context. Spatial ability is crucial for thought processing and problem-solving in engineering, mathematics, and other sciences at every level [4], [5], [6].

Sorby [7] stated that spatial visualization skills can be trained and improved further with regular classroom activities. In fact, Sorby [8] tested the effectiveness of spatial visualization skill training and found that it directly led to improved overall student scores and retention. Additionally, Dong and El-Sayed [9] demonstrated that early assessment of students' spatial ability within a course can contribute to improved academic performance across multiple mechanical engineering courses and facilitate first-year students' transition into college.

Veurink and Hamlin [10] investigated the relationship between first-year students' spatial ability, their confidence in their spatial ability, and their confidence in their chosen major across a range of disciplines. Veurink and Sorby [11] further explored the same sample data to compare student performance across a variety of engineering disciplines. However, while these studies provide valuable insights into performance and confidence, they do not explicitly examine how students themselves perceive the importance of spatial ability within their chosen fields. The present study addresses this gap by conducting a comparative analysis that integrates student performance data with qualitative responses to an open-ended question regarding the perceived importance of spatial ability in their respective disciplines.

Despite the extensive body of research linking spatial ability to academic performance and persistence in engineering, there is a notable absence of studies that directly explore students' own perceptions of the importance of spatial ability and how these perceptions correspond to their performance. This relationship may influence motivation, self-efficacy, and engagement.

1.1 Purpose of the Study

This study aims to answer the following questions: (a) How does the spatial ability of students in a first-year introductory engineering course vary across different majors? (b) To what extent do the students' perceptions of the importance of spatial ability align with their spatial ability? and (c) What themes emerge from the students' responses related to their perceptions of the importance of spatial ability in relation to their chosen major? This convergent mixed method study is to compare extracted themes in students' open-ended responses on the importance of spatial ability to their majors and their scores on the Revised PSVT:R.

2. Literature Review

2.1 Spatial Ability and Engineering Majors

Veurink and Hamlin [10] assessed the spatial abilities of first-year engineering students across different majors, using the PSVT:R and analyzed their effect on engineering students' confidence at the start and end of the first academic year. The authors also compared the spatial skills of students across different majors to explore whether these abilities affected their choice of a major. They concluded that spatial ability significantly influenced engineering students' confidence and potentially their choice of major. Additionally, mechanical engineering students demonstrated the highest spatial ability scores across all majors. Overall, the findings suggested that a student's spatial abilities played a meaningful role in shaping both confidence and major decisions.

Additionally, Veurink and Sorby [11] conducted a comparative analysis of PSVT:R and ACT mathematics scores across engineering majors. ACT mathematics scores were used as a benchmark to assess math scores across departments. Results indicated that, with the exception of Chemical Engineering, all examined disciplines demonstrated significantly higher ACT math scores than Materials Science Engineering students. On the other hand, analysis of PSVT:R scores revealed that students in Mechanical, Computer, Electrical, and Chemical Engineering scored significantly higher than their Materials Science Engineering counterparts, while the remaining engineering disciplines did not show significance. Veurink and Sorby [11] findings further supported the relationship identified by Veurink and Hamlin [10], suggesting that students' academic backgrounds are associated with their spatial ability development. Both studies emphasized the importance of developing spatial abilities early to enhance student success and retention in engineering fields [10], [11]. However, Veurink and Hamlin's [10] reliance on a Likert scale limited a deeper examination of students' perceptions of spatial ability and how these perceptions relate to their chosen major.

2.2 Student Motivation and Spatial Ability

Previous studies have attempted to connect student motivation and perceptions of spatial ability to their performance. Bairaktarova et al. [12] collected Revised PSVT:R data from first-year, upper-year, and graduate engineering students as well as nondescript working professional engineers. The survey attempted to explore a relationship between Revised PSVT:R scores and demographic, experiential, and motivational questions, including self-efficacy and perceived importance.

The study found that spatial ability differed significantly by gender, with additional differences observed across age and ethnicity, while no statistically significant differences emerged based on participant classification, experience, or academic major within the STEM-focused sample. It should be noted that student participants' majors were limited to Aerospace Engineering, Electrical Engineering, Mechanical Engineering, Construction Science, Chemical Engineering, Petroleum Engineering, and Industrial Engineering. Additionally, differences in spatial ability between first-year and upper-year students were not examined, as all majors were treated as separate groups regardless of academic year.

Regarding motivational data, results indicated some statistically significant correlations between overall motivation and spatial ability performance. However, perceived importance was reported to be not significantly related. The authors did note that perceptions were compiled and operationalized indirectly through predefined survey items rather than eliciting students' own articulated open views on the importance of spatial ability. Data on both performance scores and the importance of spatial ability comparisons did not distinguish between student age or academic year. Therefore, further research highlighting articulate complete responses for isolated academic years could yield stronger significance.

3. Method

3.1. Setting and Course Description

Students enrolled in an introductory engineering course participated in the study during the first week of the 2025 Fall semester at a large R1 public university in the U.S. Midwest. The course is a mandatory foundational course for a range of engineering and engineering technology majors, but a range of exploratory students from other colleges, such as business management, liberal arts, and public health majors, also took the course. The course aims to teach and supplement students' valuable skills in spatial ability, coding, and basic statistics. In Fall 2025, 1,344 students were registered in the course at the start. For incentives, students who participated in the survey were compensated with points equivalent to one home assignment.

3.2 Instrument

Several spatial tests were developed to assess different types of spatial visualization skills [13]. One commonly used spatial test is the Revised Purdue Spatial Visualization Test: Visualization of Rotations (Revised PSVT:R), originally designed by Guay [14] and revised by Yoon [15]. A survey was constructed to collect student spatial ability using the Revised PSVT:R spatial test, student responses to an open-ended question about how important they perceive the spatial ability used in the test is to their major, relevant education backgrounds, and personal demographics. The Revised PSVT:R consisted of 30 multiple-choice questions focused on the spatial visualization in the three-dimensional mental rotations. Each question gives an isometric view of a 3D object that is rotated to a new position. Test participants are given a second 3D object and are meant to match its rotation to the first object. Each question gives five answer options with only one correct answer. The Revised PSVT:R was chosen because of (a) its rigorous validity and reliability evidence as a spatial test and (b) its relevance to spatial tasks in STEM education [15]. The Revised PSVT:R has strong internal consistency (Cronbach's α = 0.862 [15], 0.839 [16], 0.802 [17]), indicating that most score variance is attributable to true score differences.

3.3 Participants

While there were 1,336 respondents, excluding respondents who did not consent to study participation but participated only for home assignment grade, duplicate, incomplete, and invalid submissions (e.g., all answers were C), resulted in a total of 1,166 valid respondents (87.3% response rate). Table 1 reports their demographic and disciplinary backgrounds.

Table 1. First-Year Student Background Characteristics (*N* = 1,166)

Category	**Subcategory**	***n***	**%**
Gender	Female	240	20.6
	Male	923	79.2
	Unknown	12	1.0
Ethnicity	American Indian or Alaska Native	1	0.1
	Asian	72	6.2
	Black or African American	69	5.9
	Hispanic/Latino	70	6.0
	Non-Residents	110	9.4
	Two or more races	71	6.1
	Unknown	28	2.4
	White	755	64.8
Major	Aerospace Engineering	90	7.7
	Architectural Engineering	45	3.9
	Biomedical Engineering	62	5.3
	Chemical Engineering	75	6.4
	Civil Engineering	85	7.3
	Computer Engineering	30	2.6
	Computer Science	90	7.7
	Construction Management	58	5.0
	Cybersecurity Engineering	14	1.2
	Electrical Engineering	71	6.1
	Electrical Engineering Technology	13	1.1
	Environmental Engineering	15	1.3
	Industrial and Systems Engineering	17	1.5
	Mechanical Engineering	236	20.2

	Mechanical Engineering Technology	57	4.9
	Pre-Engineering	8	0.7
	Undecided Engineering Major	83	7.1
	Exploratory	105	9.0
	Unknown	12	1.0
	*Other	10	0.9

Note. *Other = a sum of all majors with fewer than five students.

Table 1 indicates that the majority of the participants were from mechanical engineering with 20.2%. The majority of participants had an engineering major declared, and a few non-engineering students were included. Majors that do not have more than five participants are combined into the "Other" category to allow quantitative analysis. Majors that fall in the "Other" category include students with non-engineering majors, such as Chemistry, Environmental Studies, Industrial Management, Nuclear Medicine Technology, Operations Management, Public Health, Business Administration, and the Liberal Arts Program.

3.4 Data Analysis

This study employed a convergent mixed methods analytical framework to compare students' responses to an open-ended question with their corresponding survey scores across multiple academic majors. Descriptive statistics were generated for all quantitative measures to provide an overall profile of student performance. Furthermore, descriptive statistics were separated by student major to identify patterns or group-level differences. To examine whether statistically significant differences exist among student majors, a one-way analysis of variance (ANOVA) was conducted on the Revised PSVT:R scores, followed by a Tukey post-hoc test to confirm the results.

The qualitative component involved two levels of coding for the open-ended responses. The first level coding classified all responses as "Yes," "No," or "Unsure," regarding their perceptions of the importance of spatial ability in their major, ensuring that the full dataset is represented in the qualitative analysis. For the second level coding, a grounded-theory thematic analysis was used to identify and categorize emergent themes from the open-ended responses. This analysis included both the frequency of themes and the frequency with which each major reported those themes, if any.

Finally, qualitative and quantitative findings were integrated to assess convergence or divergence between students' thematic responses, their academic major, and their Revised PSVT:R performance. This integration provided a more comprehensive understanding of how students' perceptions and cognitive responses align with measurable performance outcomes across academic disciplines.

4. Results

4.1 Student Spatial Ability by Major

Students scored moderately on the test overall (n = 1,166, M = 19.55, SD = 6.34) in the range from 1 to 30. 24 (2.1%) of students received a perfect score. According to Figure 1, Mechanical Engineering and Aerospace Engineering equally demonstrated the highest mean performance (M = 21.53), with Electrical Engineering (M = 21.41) and Architectural Engineering (M = 21.36) in third and fourth, respectively. Several majors shown in Figure 1 exhibit non-overlapping confidence intervals, suggesting significant mean differences on the Revised PSVT:R scores.

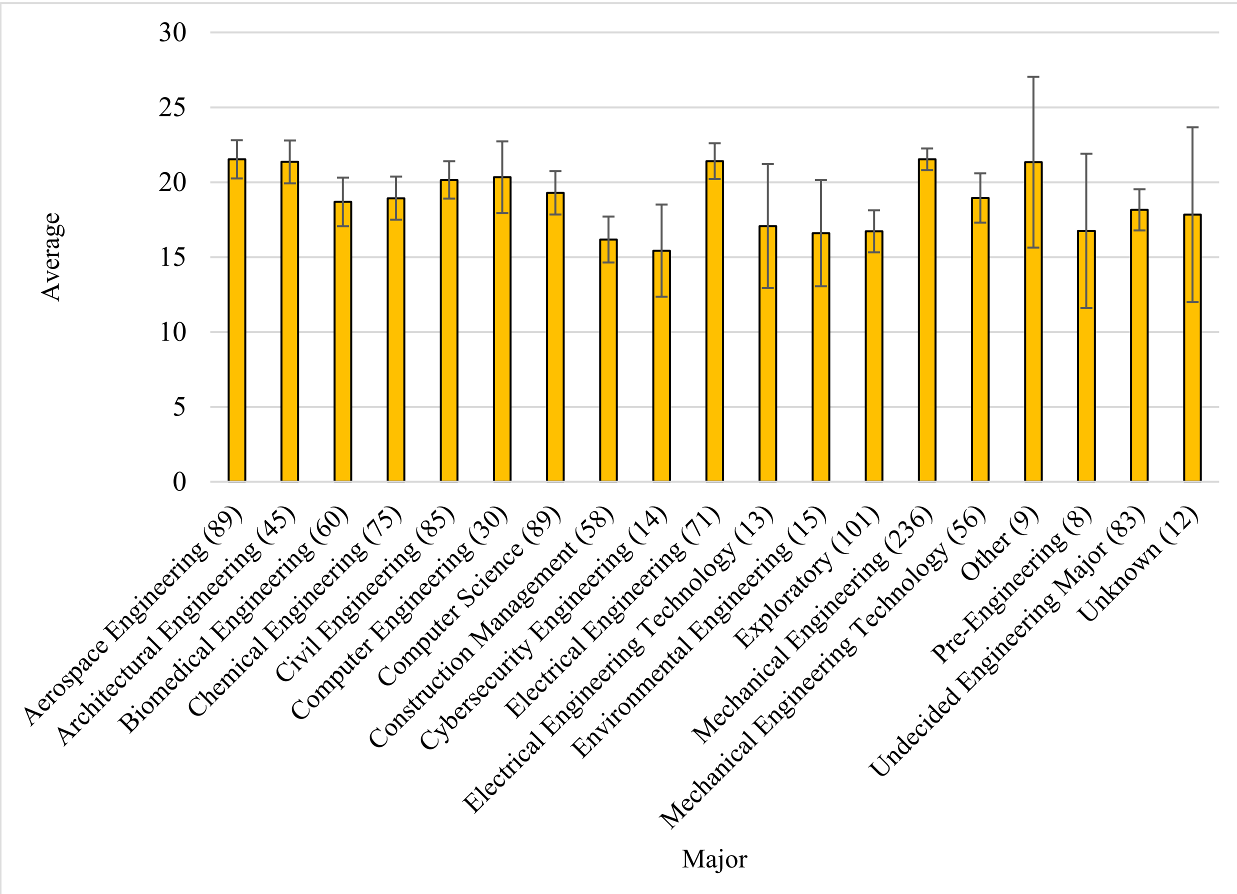

Figure 1. Mean Revised PSVT:R scores with 95% confidence intervals by major

Table 2 presents the results of a one-way ANOVA examining differences in test performance across majors. The analysis revealed a statistically significant overall effect of major on student performance, $F(18, 1{,}130) = 5.96$, $p < .05$, indicating that mean Revised PSVT:R scores varied across majors. Tukey HSD post hoc comparisons indicated that students in Construction Management and Undecided majors scored significantly lower than five other majors.

Table 2. One-Way ANOVA of Student Revised PSVT:R Scores by Major

Source of Variation	***SS***	***df***	***MS***	***F***	***p***	**F crit**
Between Groups	4018.68	18	223.26	5.96	< 0.001	1.61
Within Groups	42327.61	1130	37.46			
Total	46346.29	1148				

4.2 Student Spatial Ability by Perception of the Spatial Ability Importance

Toward the end of the survey, students responded to an open-ended question that asked: *"Do you think this type of spatial visualization skill is important to your current field of study or major? Please describe in detail why or why not. Feel free to reference any specific tasks, classes, or real-world situations where this kind of thing might (or might not) be useful."* Student responses to the open-ended question were categorized into three groups: 'Yes', 'No', and 'Unsure'.

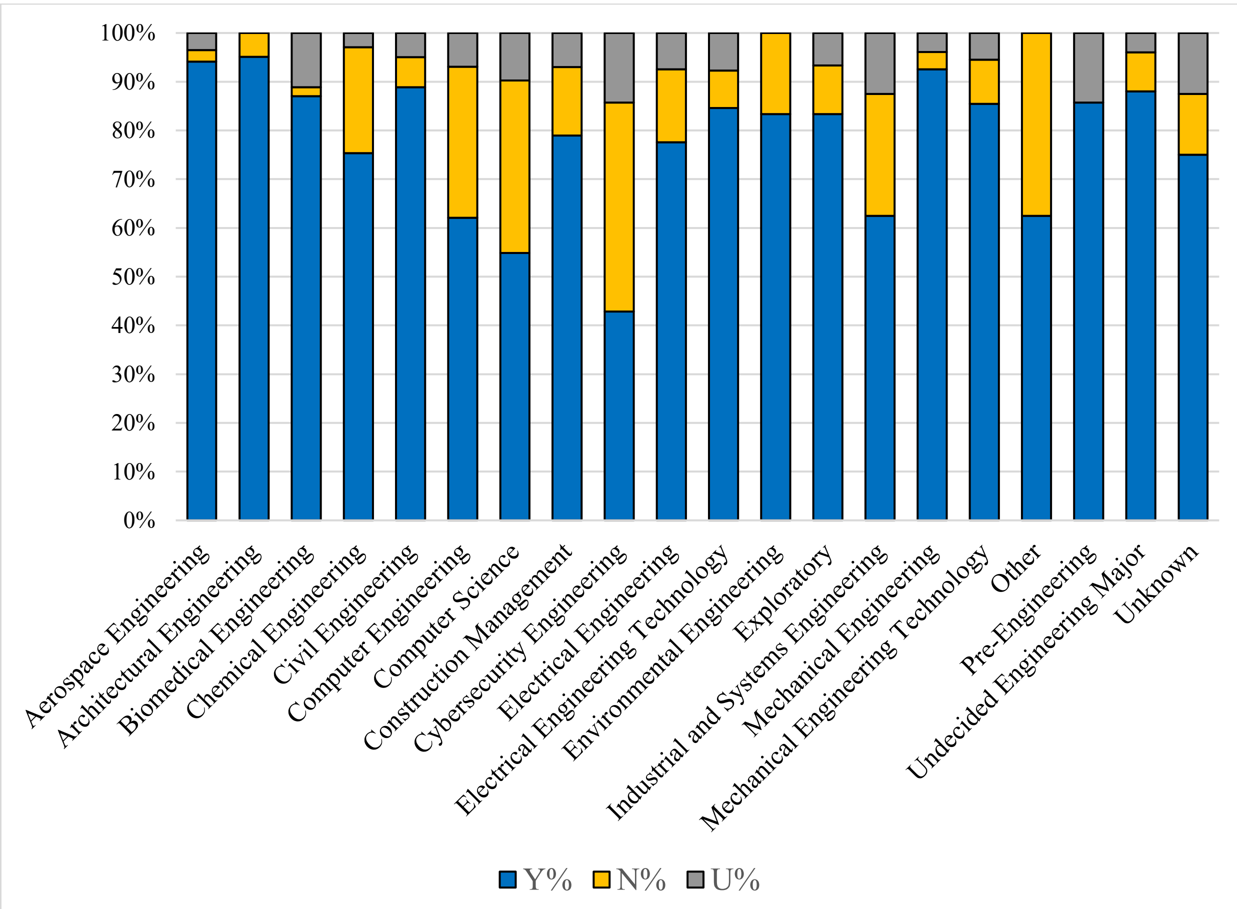

Figure 2. Yes/No/Unsure responses in percentage per major to the spatial ability importance question

Responses that explicitly indicated agreement or disagreement were classified accordingly. Responses were coded as 'Yes' if students provided a clear affirmative answer, describing potential applications of spatial ability generally, within their field, or implying the relevance of spatial ability to their major. Responses were coded as 'No' when students provided a clear negative answer. To minimize assumptions, responses were categorized as 'Unsure' when students described spatial ability in both positive and negative terms, in neither positive nor negative terms, or when responses were too vague to be reliably classified as 'Yes' or 'No'. Responses were still considered from students who did not have a valid or complete the Revised

PSVT:R. Blank, gibberish, or explicitly comical responses were excluded. Figure 2 shows the perception categories per major.

Table 3 shows the descriptive statistics of student performance on the Revised PSVT:R based on their perception. The results are also displayed in Figure 3 with a 95% confidence interval. Table 4 presents the results of a one-way ANOVA examining differences in the Revised PSVT:R scores between student responses. ‘Yes’ students scored the highest average, ‘No’ students scored the second highest, and ‘Unsure’ students scored third. The ANOVA confirms significant differences among the means, and Tukey HSD post hoc comparisons showed the only significant difference between students who answered ‘Yes’ and ‘Unsure.’

Table 3. Student Revised PSVT:R Scores by Their Perception of the Importance of Spatial Ability

Group	***n***	***M***	***SD***	**Med**	**Mode**
Yes	906	19.91	6.22	21	20
No	126	18.60	6.54	19	21
Unsure	62	16.89	6.89	16.5	16

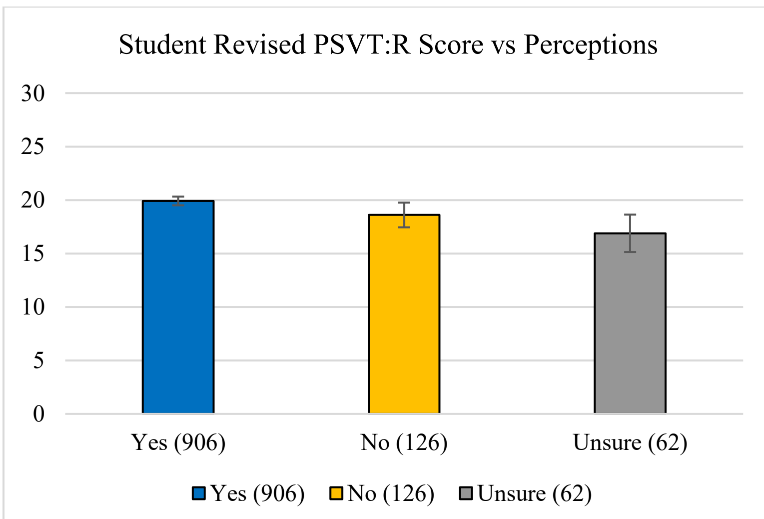

Figure 3. Mean Revised PSVT:R scores by student perceptions of the spatial ability importance

Table 4. One-Way ANOVA of Student Revised PSVT:R Scores by Their Perception of the Importance of Spatial Ability

Source of Variation	***SS***	***df***	**MS**	***F***	***P***
Between Groups	670.71	2	335.35	8.46	< .001
Within Groups	43235.65	1091	39.63		
Total	43906.36	1093			

4.3 Themes Present in Student Responses

Student responses to the open-ended question were coded according to consistently occurring themes. Table 5 presents the identified themes, their definitions, and examples of what would fall under that definition.

Table 5. Eight Themes Emerged from Student Perceptions of Spatial Ability Importance

Theme	**Definition**	**Example keywords and topics**
A. Spatial visualization as core to engineering practice	Students perceive spatial visualization as fundamentally embedded in engineering work, particularly for understanding and manipulating physical forms, systems, and perspectives. This theme reflects a belief that spatial thinking is intrinsic to engineering cognition and practice.	• Engineers work with complex shapes/angles • Engineers need to visualize things from all angles/POVs • Systems or parts fitting, assembling, moving, or interacting • Problem solving, prototyping, testing, and idea development
B. Application to technical tools and representations	Students connect spatial skills to the use and interpretation of formal engineering tools and representations. This theme emphasizes design and applied contexts, where spatial ability is seen as enabling interaction with disciplinary tools and coursework.	• CAD/3D modeling • Reading or creating designs, plans, or blueprints • Course-specific applications (e.g., circuits, robotics, sensors, etc.)
C. Cognitive skill development and transferability	Students frame spatial visualization as a broader cognitive or intellectual skill with value beyond specific tasks. Spatial skills are conceptualized as generalizable mental abilities, supporting learning, creativity, and adaptability across domains.	• Imagination and cognitive ability • Another skill worth having, generally • Defining spatial abilities and their benefits
D. Instrumental and professional utility framing	Students link spatial skills to efficiency, productivity, or professional success metrics, especially in a business sense and workplace effectiveness.	• Business, financial budgeting, production efficiency, and/or time importance
E. Perceived general importance without specific justification within or outside of their discipline	Students affirm the importance of spatial skills but provide limited or vague explanations. This theme may indicate surface-level endorsement or socially expected responses without a deeply internalized understanding.	• Important, but not sure how • General importance in the field with no detail or use • Sees the benefit for other engineers, other than themselves • It is beneficial for all, regardless
F. Perceived lack of relevance to personal academic or career context	Students explicitly state that spatial visualization is not important for their major, expected work, or personal experience. This theme highlights misalignment between perceived skill demands and disciplinary identity, which may impact motivation to engage with spatial training.	• Not important because of the major • Not important because of expected work • Expected work limited to 2D • No personal use • Never seen the concept before or cared for it
G. Conditional or context-dependent relevance	Students perceive spatial visualization as important only in specific fields, roles, or situations. This reflects how spatial skills may be valuable, but not universally	• Niche or specific field uses • Not at the test's difficulty level

	required across all contexts or proficiency levels.	
H. Technological substitution of spatial skills	Students believe modern tools reduce or eliminate the need for individual spatial reasoning ability. This theme reflects a technology-replacement mindset, where cognitive effort is perceived as outsourced to software.	• CAD/AI/3D modeling software does the job for me

Table 6 presents a matrix of themes and counts how many of each major's responses fall within each theme. Some responses fit into multiple themes and were therefore counted in all. Responses were only considered for analysis if students wrote a complete response to the question beyond a simple yes or no.

Table 6. Frequency of the Eight Themes on the Spatial Ability Importance by Major

Major	**Frequency of the Themes**							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Aerospace Engineering	46	36	9	7	8	1	1	1
Architectural Engineering	23	14	3	0	7	0	0	1
Biomedical Engineering	29	28	11	0	3	1	2	0
Chemical Engineering	37	10	7	5	13	13	1	0
Civil Engineering	38	27	7	3	6	1	4	4
Computer Engineering	6	12	5	2	5	7	3	0
Computer Science	23	15	11	1	11	24	12	5
Construction Management	22	20	1	7	7	5	1	3
Cybersecurity Engineering	5	1	1	1	3	5	2	1
Electrical Engineering	31	26	16	3	7	9	4	0
Electrical Engineering Technology	4	6	0	0	1	0	0	0
Environmental Engineering	3	0	1	1	2	1	1	0
Exploratory	36	30	16	6	10	4	2	0
Industrial and Systems Engineering	5	2	2	1	5	4	1	0
Mechanical Engineering	98	84	37	12	24	4	4	2
Mechanical Engineering Technology	30	17	9	1	6	1	1	5
Pre-Engineering	4	3	1	1	2	0	0	0
Other	2	1	2	0	2	2	0	0
Undecided Engineering Major	32	25	9	3	14	3	2	1
Unknown	5	4	3	1	2	1	3	0
Total	479	361	151	55	139	87	44	23
%Total	35.8	27.0	11.3	4.1	10.4	6.5	3.3	1.7

5. Discussion

5.1 Student Spatial Ability by Major

Regarding student majors, student performance on the Revised PSVT:R, shown in Figure 1, yielded results similar to those of Veurink and Sorby (2012). Majors that are typically considered highly visual engineering fields, such as Mechanical Engineering, Aerospace Engineering, and Architectural Engineering, scored significantly higher than less visually demanding majors, such as Cybersecurity Engineering, Construction Management, and Environmental Engineering. Exploratory and Pre-Engineering students were also on the lower end of the results, but not as significantly as the three lowest-scoring majors. Student spatial ability varies significantly based on student majors. One explanation for this is the same suggestion by Veurink and Hamlin (2011), where students might be drawn to the major because of their spatial ability and their confidence in that ability.

5.2. Student Perceptions of the Importance of Spatial Ability by Major and Their Revised PSVT:R Scores

As demonstrated by Figure 2, Aerospace, Architectural, and Mechanical Engineering majors have shown the highest percentage of agreement on the importance of spatial ability in their field. Students who agreed with the importance of spatial ability in their field seem to mostly recognize that their majors require spatial abilities for both their college studies and within their industry. This is also evident in how students who agreed with the statement scored higher on the Revised PSVT:R than students who disagreed. However, there is no statistical significance between 'Yes' and 'No' respondents' scores. Cybersecurity Engineering students have the lowest 'Yes' percentage, which is an equal percentage of 'Yes' and 'No' responses. Cybersecurity Engineering and Pre-Engineering students are also tied for the highest percentage of unsure responses. Therefore, 'Unsure' engineering students' poor performance on the Revised PSVT:R could be related to those majors' perception of spatial ability.

5.3 Themes Present in Student Responses on the Importance of Spatial Ability

These responses showed varying levels of understanding of how, when, where, and why a spatial ability may be used. The most prevalent theme across all majors, especially 'Yes' respondents, included students realizing that spatial visualization is core to engineering practices. The second most prevalent theme relating to the application of spatial ability in technical tools and representations further explained this motivation, as a large portion of student responses were about interpreting and creating designs.

A common theme was the view of students' potential for education and work in relation to other majors. 'No' students mentioned they did not expect any spatial abilities to be involved in either their education or their future line of work. Despite this, some of those respondents highlighted other majors, directly or indirectly, that they believe inherently need stronger spatial abilities, such as mechanical and civil engineering.

Students who responded with 'Yes' and 'No' have overlapping themes. A common topic discussed in the responses is the use of CAD and designs. The use of CAD is made significantly easier with strong spatial abilities [18]. Responses include themes related to the need for spatial abilities to create designs, to interpret designs, and to use CAD tools proficiently. Some responses mentioned how CAD will generally make things easier and, in some cases, nullify the need for spatial ability. The final theme listed is a significant point that could be explored further, as it may be a hindrance to student motivation in spatial ability courses.

5.4. Limitations and Suggestions for Future Research

The present study is subject to several limitations. First, the use of an open-ended question without a clear yes/no component limited the ability to categorize responses in a more structured, efficient, and quantifiable manner. Second, data collection occurred approximately two weeks into the course, at which point students may have already been exposed to course content highlighting spatial ability. This timing may have introduced potential biases and early instructional influence. Third, the dataset may still include invalid or low-quality responses that were not readily identifiable. For example, open-ended responses might not accurately represent students' true perspectives, potentially introducing noise into the data analysis. Fourth, the interpretation and coding of open-ended responses inherently involve researcher subjectivity, even when systematic procedures were applied.

Regarding future studies, we plan to explore student post-survey to explore any changes in their perceptions of the importance of spatial ability as they were exposed to various engineering disciplines during their first semester. Future studies will also further analyze student demographics and how they may relate to their responses on the importance of spatial ability, spatial ability, and course performance. Lastly, we will explore other potential factors affecting student performance through qualitative means.

5.5 Conclusion

This study revealed that students enrolled in the first-year engineering introductory course had significantly varied levels of spatial ability. Student performance on the Revised PSVT:R varied across disciplines and in relation to students' perceptions of the importance of spatial ability within those disciplines. Additionally, student responses to the open-ended question indicated different levels of understanding of how, when, where, and why spatial ability is used and expected in their major. The findings also suggest that students' perceptions of the importance of spatial ability are shaped by their expectations of both academic and professional work. These perceptions were associated with performance on the Revised PSVT:R, indicating a potential relationship between what students believe and how they perform. Future research should further examine this relationship, including the mechanisms that may explain it. More targeted studies will be necessary to determine whether and how students' beliefs about spatial ability directly relate to their assessment outcomes. Further targeted studies would be necessary to clarify whether and how students' beliefs about spatial ability relate to their assessment outcomes.

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