Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #46265

Investigating the Impact of an Online Freehand Sketching and Spatial Visualization Intervention on First-Year Engineering Students' Skills and Cognitive Development

Dr. BURCU OZDEN, Pennsylvania State University

Dr. Burcu Ozden holds a master's degree in physics education as well as a doctorate in physics. She is currently an assistant professor at Penn State Abington. Her work focuses on defects, exciton-polaritons, radiation studies, engineering education, and the integration of sustainability in engineering.

Dr. Sabahattin Gokhan Ozden, Penn State Abington

Dr. Sabahattin Gokhan Ozden is an associate professor of Information Sciences and Technology at Penn State Abington. He has a Ph.D. and MISE from Auburn University in Industrial and Systems Engineering and a B.Sc. in Software Engineering and double major in Industrial Systems Engineering from Izmir University of Economics. His research interests are warehousing, optimization, and information systems. Dr. Ozden has published in various journals/conferences including Computers and Operations Research and Naval Research Logistics. His website address is https://www.gokhanozden.com.

Investigating the Impact of an Online Freehand Sketching and Spatial Visualization Intervention on First-Year Engineering Students' Skills and Cognitive Development

Abstract

Spatial visualization skills are essential for success in STEM fields, yet many first-year engineering students struggle to develop proficiency in these critical abilities. This study investigates the impact of an innovative online freehand sketching and spatial visualization tool, Spatial Vis™, on students' spatial reasoning and cognitive skills in a first-year engineering design course. Using a mixed-methods approach, the research examines the effects of the tool through pre-and post-assessments, surveys, and qualitative interviews. The study addresses three key research questions: (1) How does the tool influence students' spatial visualization skills over the semester? (2) How does sketching with the tool enhance cognitive abilities related to spatial thinking? (3) What are students' perceptions of the tool's effectiveness in learning sketching and spatial skills? The findings reveal significant improvements in spatial reasoning, confidence, and engagement among students who used the tool, compared to a control group relying on traditional instruction. This paper discusses integrating the tool into the curriculum, its potential to foster deeper spatial understanding, and its role in bridging the gap between theoretical learning and practical applications in engineering education. By highlighting both quantitative outcomes and student experiences, the study provides actionable insights into designing and implementing digital tools to support learning in STEM disciplines.

1. Context and Background

Spatial visualization skills are essential in engineering, enabling individuals to design, model, and solve problems involving complex geometries and spatial relationships [1]. These skills involve visualizing, manipulating, and reconstructing 3D objects, which are critical for tasks such as prototyping, system modeling, and optimizing designs for functionality[2],[3]. Studies show that strong spatial skills correlate with higher graduation rates in engineering and better problem-solving abilities[4],[5],[6].

Despite their importance, many students struggle with spatial visualization due to challenges in transitioning from 2D to 3D thinking or mastering CAD tools[7]. Traditional teaching methods, such as lectures or CAD exercises, often emphasize technical proficiency but fail to foster deeper spatial reasoning or provide real-time feedback[8],[9]. Additionally, these approaches may not adequately address the needs of students with weaker foundational spatial skills or limited prior exposure to spatial activities[10],[11],[12], [13].

2. Motivation for Study

The Spatial Vis™ program offers an innovative approach to teaching spatial visualization by combining freehand sketching with guided visualizations and immediate feedback[14]. This digital tool allows students to practice tasks such as 3D rotations and perspective drawings, fostering active engagement and deeper cognitive processing[15]. However, the broader impacts of tools like Spatial Vis remain underexplored, including their influence on cognitive abilities, engagement, and long-term academic outcomes.

This study addresses gaps in research by comparing the effectiveness of Spatial Vis and traditional pen-and-paper methods in enhancing spatial reasoning. Using a mixed-methods approach—including the Revised Purdue Spatial Visualization Test: Rotations (PSVT: R), surveys, interviews, and performance analyses—it evaluates the tool's impact on cognitive skills, student engagement, and preparation for advanced CAD tools like SolidWorks. This research contributes to developing more effective and inclusive teaching practices in engineering education by providing empirical evidence.

3. Research Questions and Objectives

This study aims to investigate the effectiveness of a digital spatial visualization tool in enhancing students' spatial reasoning skills and their broader cognitive abilities. Specifically, it addresses three key research questions: (1) How does using the tool impact students' spatial visualization skills over the semester? (2) How does sketching with the tool influence cognitive abilities related to spatial thinking? (3) What are students' perceptions of using the tool to learn sketching and spatial skills? By addressing these questions, the study aims to evaluate the tool's role in fostering skill development, improving cognitive engagement, and enhancing students' confidence and interest in spatial tasks, ultimately providing insights for more effective integration into engineering education.

4. Methodology

4.1 Assessment Instruments

This study utilized a mixed-methods approach[16], combining qualitative and quantitative methods to assess students' spatial visualization skills and perceptions of the tool's effectiveness. Three primary methods were employed: the Revised Purdue Spatial Visualization Test: Rotations (PSVT: R)[17], self-developed interview questions, and assignments.

4.1.1 PSVT: R Test

The PSVT: R, a validated instrument, was used to evaluate how sketching with the tool influences spatial thinking. The test includes 30 multiple-choice questions involving 3D object rotations. A dual scoring system, 30-point, and 78-point scales—was adapted from a 2013 study to evaluate simple and complex rotations.

4.1.2 Assignments and Academic Performance

Grades from Spatial Vis modules, design projects, CAD assignments, and overall course performance were analyzed to evaluate the tool's impact. These assignments required students to apply and demonstrate their spatial visualization skills in practical contexts. A control group using traditional pen-and-paper methods completed the same PSVT: R test as a basis for comparison.

4.1.3 Surveys and Interviews

Surveys and interviews explored students' confidence, interest, and perceptions of the tool. Surveys included demographic questions and ratings of confidence in 2D and 3D drawing. Semi-structured interviews were conducted with five students who used the Spatial Vis™ tool as part of an engineering drawing course. Interviews were recorded and transcribed using Zoom™ Video Conferencing Software's AI transcription feature. Transcripts were reviewed for clarity, with minor edits to correct transcription errors and remove non-verbal filler words.

The qualitative analysis followed an inductive, theme-based approach. Transcripts were read multiple times to identify recurring patterns, observations, and reflections related to tool usability, skill development, and integration into the learning process. Key segments were manually grouped into thematic categories, including *usability and interface*, *spatial skill development*, *transition to CAD tools*, and *learning experience integration*. These themes emerged organically through close reading, comparison of participant responses, and synthesis of shared or divergent experiences. This process allowed for a comprehensive understanding of how students perceived the Spatial Vis™ tool and its impact on their learning.

4.2 Control and Experiment Groups

This intervention was implemented in a first-year engineering design course at Penn State Abington, a 4-year undergraduate satellite campus of the Penn State University located in Abington, PA, emphasizing spatial visualization skills through orthogonal and isometric drawings integrated into the curriculum.

4.2.1 Control Group

Control group students received traditional orthographic and isometric drawing instruction, followed by exercises and feedback. They learned SolidWorks™ and AutoCAD™, reinforcing spatial visualization skills. The PSVT: R test was administered pre- and post-semester, with voluntary participation. Participation was voluntary, with students receiving a gift card for participation. The group included seven participants: two identified as female, four as male, and one as nonbinary. The group included three Asian students, one Black or African student, three Asian and three White students. Only one student had prior experience with spatial visualization tests.

4.2.2 Experimental Group

The experimental group also completed the PSVT: R at the beginning and end of the semester. This group included nine students: one female, ten males, and one nonbinary student. Among them, two identified as Black or African, four as Asian, and six as White.

Students in the experimental group engaged with the Spatial Vis™[14] program, which introduced them to spatial visualization concepts through structured modules. With financial support from Pennsylvania State University's Leonhard Center, each student was issued a license to download the app to a personal touchscreen device or access the entire training package from a web browser. Spatial Vis™ was part of their curriculum. However, participating in the surveys was voluntary, and no extra credit was offered for being part of the study in any participating class. Daily lectures were complemented by in-class practice sessions, with additional modules completed outside class. To further reinforce these skills, the instructor provided office hours and integrated hands-on activities using pen and paper (detailed in Appendix B).

Twelve lecture hours and one additional week outside class were dedicated to the Spatial Vis™ modules. Following this, students transitioned to learning SolidWorks™ while working on their final design projects. These assignments were designed to translate theoretical spatial visualization concepts into practical applications, requiring students to create 3D models from 2D sketches, navigate complex geometries, and interpret multiple object views. This integration reinforced their ability to visualize spatial relationships and demonstrated the real-world relevance of these skills.

Toward the end of the semester, students learned AutoCAD™, further enhancing their ability to create and interpret technical drawings. They applied their spatial visualization skills acquired through the Spatial Vis™ program, SolidWorks™, and AutoCAD™ to complete their design projects, solidifying their understanding and practical application of these concepts.

4.2.3 Limitations and Mitigation of Bias

While the control and experimental groups were assessed using the same tools and metrics, differences in instructional delivery may have introduced biases. The experimental group was taught by an instructor familiar with the Spatial Vis™ program, while the control group used traditional pen-and-paper methods led by a different instructor. Standardized lesson objectives and materials were used to minimize these effects, and identical assessments, including the PSVT: R test and design assignments, provided a common basis for comparison. Future studies could reduce bias further by having the same instructor teach both groups or using blind assessments to evaluate student work objectively.

Demographic data, including gender, race, and prior experience, were collected but had limited representation, with some categories (e.g., Nonbinary and Black students) including only one or two participants. Due to small sample sizes, demographic comparisons were not emphasized, and the study focused on the overall impact of the Spatial Vis™ tool. Future research with larger, more diverse samples could better explore the influence of demographic factors on spatial visualization skill development.

4.3 Spatial Vis™ Modules

In the Fall of 2024, students engaged with the Spatial Vis™ [15] program starting in the second week of the semester for approximately four weeks. During the first three weeks, students completed assignments during class, while the fourth week required independent work outside of class. Dedicated "spatial office hours" were offered during this period, though only a few students utilized them.

The Spatial Vis™ program organizes assignments by difficulty levels: "light-load," "curated mid-load," and "mid-load," with increasing complexity and time requirements. Teachers can also create custom assignment sets tailored to their class needs.

Students completed ten modules, beginning with an introductory module to familiarize themselves with the program's interface and functionality. Subsequent modules focused on spatial reasoning skills, including rotating 2D objects, sketching isometric and orthographic views, rotating 3D objects around axes, assembling 3D objects, and sketching flat patterns that fold into shapes. Each module functioned as a "spatial gym," progressively developing students' mental visualization skills.

Before starting each module, the instructor delivered a brief 10–15-minute lecture introducing key concepts. Students then worked on 30–35 activities per module, solving problems by sketching directly on a touchscreen device or using a mouse. The software graded sketches instantly, providing feedback with options to retry, request hints, or preview solutions. Instructors were available during class to assist students as needed.

Brief video tutorials supplemented the modules to further aid understanding, explain foundational concepts, and offer worked examples. The program’s structured progression from simple to complex problems effectively reinforced spatial skill development. Modules on Isometric Drawing, Orthogonal Drawing, Rotation, and Assembly were paired with hands-on activities (detailed in the Hands-On Activities section), allowing students to apply and solidify their learning through practical engagement.

Figure 1 - Spatial Vis™ Program [14]

4.4 Assignments Relevant to Spatial Visualization Skills Teaching

The course included hands-on activities, a mini design project, CAD assignments, and a final design project to build spatial skills. These assignments were scaffolded to ensure that skills introduced early were reinforced and expanded upon.

4.4.1 Hands-on Activities Relevant to Spatial Vis Program

The hands-on activities developed by eGrove Education were integral to the course and complemented the Spatial Vis™ program. While some activities followed the original design, the instructor slightly modified others to align with course goals. These activities offered students practical, interactive opportunities to apply spatial reasoning skills, enhancing their understanding through tactile and visual engagement.

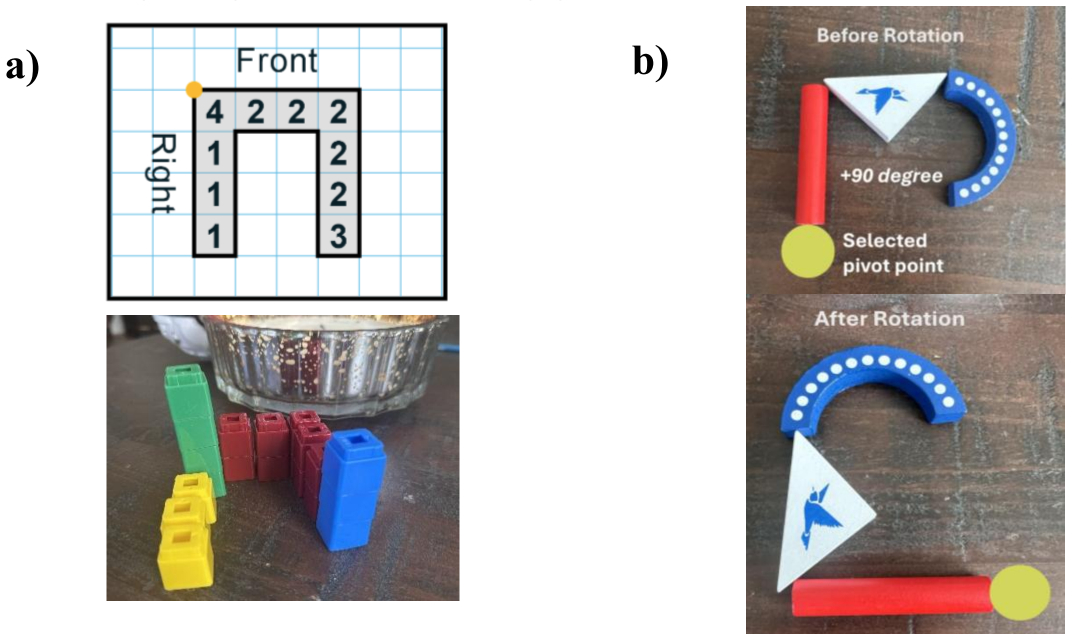

Figure 2: (a) Example of top-view plans from the Lesson 2 module in the Spatial Vis™ program [15], alongside an image of the corresponding hands-on activity where students constructed isometric views using snap cubes. (b) Illustration of a hands-on activity where students used wooden pieces to practice identifying the pivot point, rotation degree, and direction, reinforcing their understanding of spatial transformations and rotations.

The first activity, introduced after Lesson 2, involved students constructing isometric views from top-view plans (Figure 2a) using snap cubes. They oriented the structures, ensured proper alignment, and drew corresponding isometric projections, reinforcing the transition from 2D to 3D visualization.

The second activity, conducted after Lesson 3, was a collaborative exercise where pairs of students created isometric shapes with snap cubes. Each partner drew the corresponding orthographic projection, fostering teamwork and spatial reasoning with immediate peer feedback.

After Lesson 7, the final activity involved wooden geometric shapes (Figure 2b). Students combined pieces into composite structures, specified a rotation axis and angle, and their partners visualized and executed the transformation. This exercise deepened their understanding of spatial transformations and rotations.

These ungraded activities provided iterative learning opportunities, with feedback from peers and the instructor, preparing students for more advanced assignments and projects later in the course.

4.5 Mini Design Project: Puzzle Cube

The mini-design project complemented the Spatial Vis™ program by allowing students to apply spatial visualization and CAD skills in a real-world challenge. Completed individually and primarily outside of class, students used magnetic cubes during the initial prototyping phase, leveraging foundational skills in SolidWorks™ gained through earlier lessons.

The goal was to design and create a 2.25-inch puzzle cube prototype within specific constraints. Students sketched unique pieces, built and tested low-fidelity prototypes with magnetic cubes, and refined their designs based on functionality and assembly insights. Final designs included detailed 2D multi-view sketches with dimensions, digitally assembled CAD models in SolidWorks™, and 3D-printed prototypes for hands-on experience in rapid prototyping and advanced manufacturing techniques.

The project concluded with a one-page write-up documenting the design process and unique features. This activity reinforced spatial visualization, design iteration, CAD modeling, and prototyping skills, bridging the gap between theoretical concepts and practical applications.

4.6 CAD Assignments: SolidWorks Part Challenges

The CAD assignments complemented the Spatial Vis™ program by teaching key SolidWorks™ features through six practical design challenges focused on sketching, defining parts, and advanced modeling tools.

For each assignment, students applied techniques learned through the Spatial Vis™ program to create initial design sketches, including isometric and orthographic drawings. These sketches helped students visualize their concepts and plan their modeling process in SolidWorks™. They then selected one design to develop into a 3D part, focusing on fully defining sketches, ensuring proper orientation, and utilizing the assigned SolidWorks™ feature. The assignments emphasized independent learning and required students to apply their skills creatively, such as designing functional or decorative objects.

These tasks reinforced spatial visualization skills while introducing technical CAD concepts. Assignments culminated in submissions, including sketches, screenshots, and SolidWorks™ files, with peer feedback and presentation opportunities.

4.7 Final Design Project

The final design project was a four-week group assignment where teams of 3-4 students redesigned campus spaces—such as classrooms, bathrooms, pathways, and the library—to enhance inclusivity. The project emphasized a "big picture" approach, focusing on empathy, accessibility, and sustainability to address real-world challenges beyond traditional design tasks.

Teams selected prompts and followed a structured design process, iterating their solutions three times. Weekly progress was documented in design notebooks, with brief verbal updates to refine ideas based on feedback. Students sketched extensively during ideation to visualize spatial relationships and functional layouts, transitioning from abstract concepts to concrete solutions.

Prototyping further developed spatial reasoning as students created 2D alpha prototypes focused on layout and scale, then progressed to physical models using materials like cardboard and 3D-printed objects. This transition from 2D to 3D reinforced their understanding of spatial relationships and design construction.

By integrating inclusive design principles with hands-on prototyping and iterative improvement, the project provided valuable experience in user-centered design and problem-solving, equipping students with essential skills for engineering and design careers.

5. Study Findings and Implications

This section presents findings from both quantitative and qualitative analyses, starting with survey results and performance outcomes in spatial visualization assignments, followed by insights from student reflections and feedback.

5.1 Data-Driven Insights

The following sections delve into the quantitative and qualitative findings of the study. Quantitative analyses focus on pre-and post-test results, performance metrics, and statistical comparisons to evaluate the tool's impact on spatial visualization skills. Meanwhile, qualitative insights offer a deeper understanding of student experiences and perceptions of the tool, providing context to the numerical data. Together, these analyses paint a comprehensive picture of the Spatial Vis™ tool's effectiveness in fostering cognitive and practical skills in spatial reasoning.

5.1.1 Assessing the Role of Spatial Vis™ in Enhancing Spatial Thinking and Course Outcomes

This study aimed to answer the research question: "How does sketching with the Spatial Vis™ tool influence cognitive abilities related to spatial thinking?" The results are summarized in Tables 1 and 2 for the experimental and control groups. Three paired sample t-tests were conducted to analyze the data: one for the experimental group, one for the control group, and one comparing the improvements between groups. Cohen's d was also calculated for both the experimental and control groups to quantify the effect sizes, providing a standardized measure of the magnitude of the observed differences.

Table 1: *The experimental group made significant improvements after the intervention.*

Experimental Group	**Pre-Test (max 78 pts)**	**Post-Test (max 78 pts)**
Mean	52.92	62
Variance	115.91	113.17
Observations	12	
Pooled Variance		
Hypothesized Mean Difference	0.00	
df	11	

t Stat	-3.84
P(T<=t) one-tail	0.0027
t Critical one-tail	1.80
P(T<=t) two-tail	0.0054
t Critical two-tail	2.20
Cohen's d	0.85

The experimental group, which received the Spatial Vis™ training modules, showed a statistically significant improvement from the pre-test to the post-test. The mean score increased as seen in Table 1, from $M = 52.92$ to $M = 62.00$ with a paired t-test revealing significant change $(t(11) = -3.84, p = 0.0054\ two - tailed)$. This improvement indicates that the intervention successfully enhanced spatial visualization skills over the semester. Additionally, Cohen's d equals 0.85, $indicating$ a large effect size, demonstrating a substantial practical impact of the intervention on students' spatial visualization skills.

Table 2: *The control group did not show a significant difference between pre and post-tests.*

Control Group	**Pre-Test (max 78 pts)**	**Post-Test (max 78 pts)**
Mean	50.29	52.71
Variance	140.57	241.24
Observations	7	
Pooled Variance	190.90	
Hypothesized Mean Difference	0.00	
df	6	
t Stat	-0.59	
P(T<=t) one-tail	0.29	
t Critical one-tail	1.94	
P(T<=t) two-tail	0.58	
t Critical two-tail	2.45	
Cohen's d	0.18	

In contrast, the control group, which did not receive the Spatial Vis™ training, showed only a slight statistically insignificant improvement in mean scores. $(M = 50.29\ toM = 52.71; t(6) = -0.59, p = 0.58\ two\ tailed)$ as seen in Table 2. This lack of significant improvement underscores that the observed gains in the experimental group can be attributed to using the Spatial Vis™ tool and not to random chance or external factors. Furthermore, the Cohen's $d = 0.18$ for the control group indicates a small effect size, suggesting that traditional methods had a minimal practical impact on students' spatial visualization skills.

The data demonstrates that the Spatial Vis™ tool significantly impacted students' spatial thinking abilities, as evidenced by the experimental group's greater improvement in pre-and post-test results compared to the control group. Pooled variance and t-statistic analyses further confirm that the tool effectively enhanced cognitive spatial skills, while the control group showed minimal progress, emphasizing the tool's unique contribution.

Although instructional differences between the groups may have introduced some variability, the experimental group's significant gains strongly support the hypothesis that the Spatial Vis™ tool is an effective strategy for improving spatial thinking.

We conducted a correlation analysis using Pearson's correlation coefficient to examine the relationships between CAD assignment performance, final grades, and cognitive skills (post-test scores). Post-test scores, representing students' final spatial visualization abilities, were aligned with their CAD task performance and overall course outcomes. The six CAD assignments were averaged into one metric to provide a holistic view of CAD performance. A heatmap was generated to illustrate the strength and direction of correlations, with values ranging from -1 (negative correlation) to 1 (positive correlation) and values near 0 indicating no linear relationship.

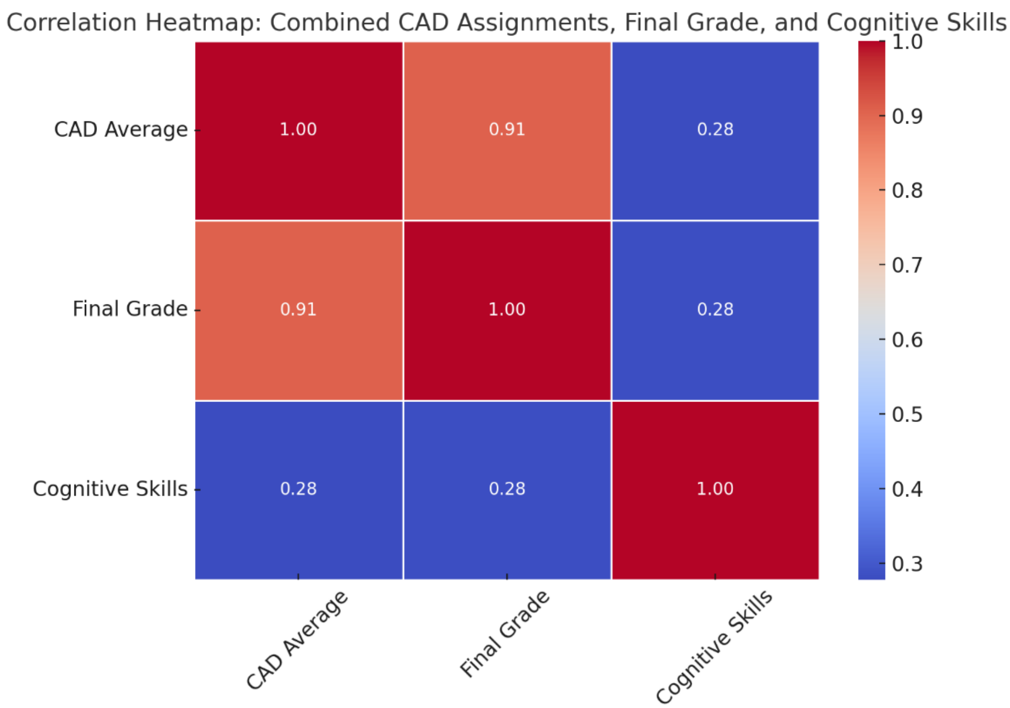

Figure 3: Correlation heatmap showing relationships between CAD assignment scores, course final grades, and PSVT: R post-test results for the experimental group. Strong positive correlations (e.g., CAD assignments and final grades, $r = 0.91$) highlight the role of spatial visualization skills in academic success. Weaker correlations (e.g., cognitive skills and CAD performance, $r = 0.28$) suggest other factors like practice and attention to detail also influence outcomes. This visualization emphasizes the multifaceted nature of performance in engineering design tasks.

The heatmap in Figure 3 highlights key relationships between CAD performance, cognitive skills, and course success. A strong positive correlation ($r = 0.91$) between CAD average and final grades suggests that strong CAD performance significantly contributes to overall course outcomes. A moderate correlation ($r = 0.28$) between cognitive skills (post-test scores) and final grades indicates that improved spatial visualization positively impacts success, though factors like effort and teamwork also play a role. Similarly, a weak positive correlation ($r = 0.28$) between cognitive skills and CAD performance suggests that while spatial visualization supports CAD success, other factors, such as CAD software familiarity and practice, are also influential. These findings underscore the multifaceted nature of academic performance in engineering.

5.1.2 Analysis of Spatial Vis Scores and Their Impact on Student Performance

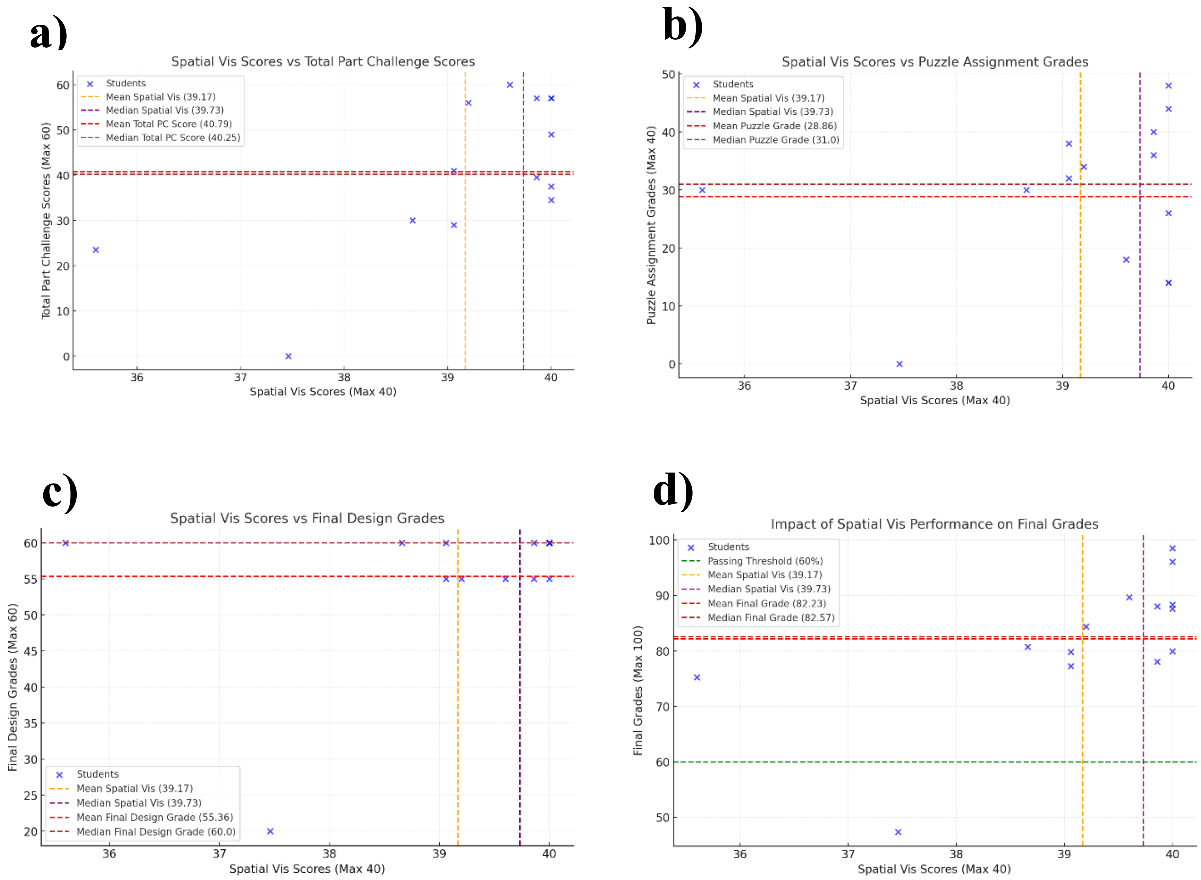

Figure 4. (a) Positive correlation between Spatial Vis™ scores and CAD assignment performance highlights the impact of spatial reasoning on technical tasks. (b) Higher Spatial Vis™ scores align with better grades on the Puzzle Cube Mini Design Project, emphasizing the importance of spatial skills in practical design challenges. (c) Spatial Vis™ scores strongly predict Final Design Project performance, showcasing their role in complex design tasks. (d) A moderate correlation between Spatial Vis™ scores and final course grades indicates that spatial skills, while critical, are part of broader factors affecting overall academic success.

The analysis of Figure 4 reveals key relationships between Spatial Vis Scores (SVS) and various performance metrics. In Figure 4.a., students with higher SVS (max: 40) generally achieved better Total Part Challenge Scores (TPCS, max: 60), indicating that spatial reasoning developed through the tool directly supports technical design tasks like SolidWorks™ assignments. Figure

4.b. shows that students with higher SVS performed better on the Puzzle assignment, demonstrating the tool's role in refining spatial reasoning and translating ideas into 3D designs. However, incomplete components like 3D printing or assembly occasionally led to lower grades, emphasizing the need for balanced technical skills and execution.

In Figure 4.c., students with higher SVS consistently earned higher Final Design Grades (FDG, max: 60), highlighting the tool's impact on complex design tasks. Some students with lower SVS still performed well, suggesting that factors like teamwork and creativity also play a role. Figure 4.d. shows a moderate correlation ($r = 0.62$) between SVS and Final Grades (FG, max: 100),

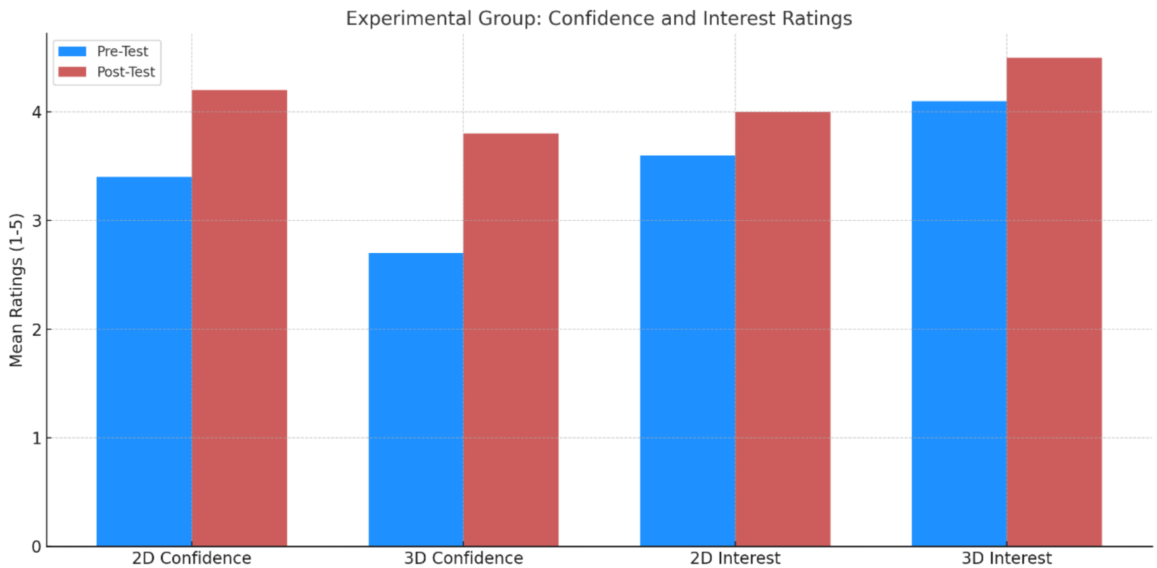

Figure 5: Pre-test and post-test mean ratings of confidence and interest in 2D and 3D drawing for the experimental group. The results show significant improvements in 2D and 3D confidence and increases in interest, particularly in 3D drawing, following the Spatial Vis™ intervention.

reinforcing that spatial skills contribute significantly to academic success.

Overall, the findings confirm the Spatial Vis™ tool's effectiveness in enhancing spatial visualization skills, supporting performance in specific assignments, and preparing students for comprehensive design tasks. While spatial skills are critical, creativity and collaboration influence success, especially in open-ended problem-solving. These results validate the program's role in improving spatial reasoning and its broader impact on academic performance.

5.1.3 Evaluating the Impact of Spatial Vis on Student Confidence and Engagement in 2D and 3D Drawing

This analysis aimed to evaluate the impact of the Spatial Vis™ intervention on students' confidence and interest in 2D and 3D drawing skills. Participants rated their confidence and interest levels on a scale of 1 to 5 before and after the intervention. The data for this analysis was generated by calculating the mean ratings of participants' responses for each category (e.g., 2D confidence, 3D interest) before and after the intervention. For each question, the ratings from all participants in the experimental and control groups were averaged to compute a single mean value. The experimental group, which received the Spatial Vis™ training, demonstrated noticeable improvements in all categories, whereas the control group showed only modest changes.

For the experimental group, as seen in Figure 5, confidence in 2D drawing increased from a mean of 3.4 in the pre-test to 4.2 in the post-test, while confidence in 3D drawing showed a significant rise from 2.7 to 3.8. Interest in 2D drawing increased slightly from 3.6 to 4.0, and interest in 3D drawing improved from 4.1 to 4.5.

For the control group, as seen in Figure 6, confidence in 2D drawing increased from 3.5 to 4.33, and confidence in 3D drawing improved from 3.0 to 4.33. However, interest levels remained relatively stable, with 2D drawing interest remaining at 3.67 before and after and 3D drawing interest increasing slightly from 3.67 to 3.83.

Overall, both groups showed improvements in confidence for 2D and 3D drawing, with the experimental group showing a more pronounced increase in confidence for 3D drawing. Interest levels in drawing increased slightly for both groups, with the experimental group showing a more notable improvement in interest in 3D drawing.

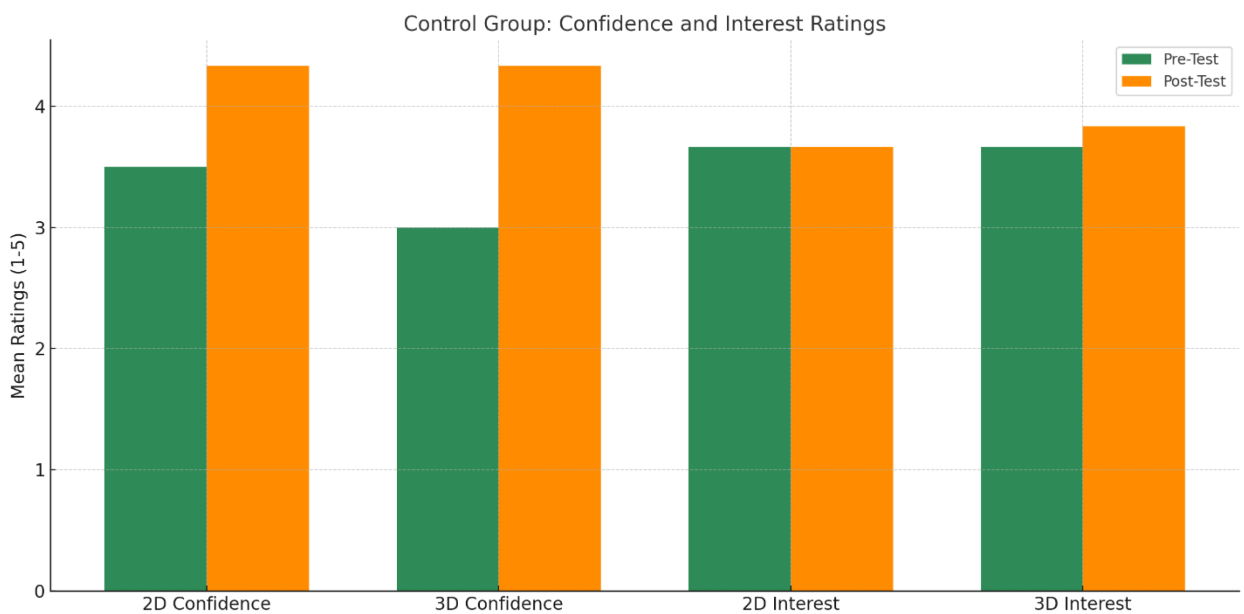

Figure 6: Pre-test and post-test mean ratings of confidence and interest in 2D and 3D drawing for the control group. While modest improvements are observed in 2D and 3D confidence, interest levels in 2D and 3D drawing remained relatively stable, highlighting the limited impact of traditional instruction without the Spatial Vis™ intervention.

5.2 Qualitative Insights

This section addresses the research question: What are students' perceptions of using the Spatial Vis™ tool to learn sketching and spatial skills? The interviews offered qualitative perspectives on the tool's usability, effectiveness in developing spatial visualization skills, and its role in preparing students for advanced design software like SolidWorks™ and AutoCAD™. Students shared candid reflections on the tool's strengths, limitations, and suggestions for course improvement. The following subsections summarize these findings.

5.2.1 Perception of the Tool

Across the five interviews, students consistently described Spatial Vis™ as a helpful tool for learning engineering drawings. Many emphasized its role in building foundational skills and expressed appreciation for how it facilitated visualization of isometric and orthonormal shapes. At the same time, they noted specific areas for improvement, particularly regarding its interface, functionality, and role in transitioning to advanced design software.

5.2.2 Engagement and Usability

Students found the tool generally intuitive and engaging. Several appreciated features such as the grid interface, pivot point highlighting, and rotation instructions, which supported their spatial reasoning. However, some noted frustrations with the system—such as accidental triggering of hints or difficulty with login and navigation. One student mentioned that zooming out was occasionally misinterpreted as a drawing action. Overall, while the interface was regarded as helpful, minor technical issues were identified as barriers to a smoother experience.

5.2.3 Skill Development

All interviewees reported gains in spatial visualization and sketching abilities. Several stated that their confidence in drawing 2D shapes increased, and many could more effectively translate between 2D and 3D perspectives. The tool was especially effective for helping students understand the relationships between different views. However, some expressed continued difficulty drawing complex 3D shapes without the grid, indicating a reliance on visual scaffolding that may limit skill generalization.

5.2.4 Transition to Advanced Tools

Participants acknowledged that Spatial Vis™ supported their readiness for tools like SolidWorks™ and AutoCAD™, particularly in identifying geometry and design intent. However, several felt that the tool did not adequately address measurement or dimensioning, which became a challenge when transitioning to CAD software. Some students noted the need for more explicit connections between Spatial Vis™ activities and the conventions used in professional design environments. hese reflections underscore the tool’s value as a foundational learning resource while highlighting the need for a more comprehensive approach to bridge the gap to advanced software.

5.2.5 Effectiveness of the Learning Process

Students appreciated how the tool was integrated into live sessions and hands-on coursework. They found the combined use of digital and physical activities—such as sketching on paper or building models—particularly effective. Several mentioned the value of a clear feedback process and supportive course structure. Suggestions for improvement included better timeline management, more practice with measurements, and a stronger research or project-based component in the curriculum.

5.2.6 General Reflections on Using the Tool

General reflections were positive. Students felt that Spatial Vis™ enhanced their confidence and served as a valuable bridge to more advanced tools. They valued the tool for its accessibility and ability to make abstract spatial concepts more concrete. However, feedback also highlighted limitations in customization, over-dependence on the grid system, and the need for a more robust transition framework for industry-standard software. One suggestion included allowing more freeform sketching without step-by-step guidance to simulate real-world design thinking.

The interviews with students reveal that the Spatial Vis™ tool is highly valued for its ability to enhance sketching and spatial skills, particularly in 2D visualization. Students perceive it as an engaging and effective tool that prepares them for advanced design software while building confidence in their abilities. However, they also identified areas for improvement, such as addressing usability challenges, enhancing training for advanced tools, and refining course structures. These insights provide actionable feedback to optimize Spatial Vis™ in engineering drawing courses and further support students' learning experiences.

6. Conclusion

This study explored the effectiveness of the Spatial Vis™ tool in enhancing spatial visualization skills, cognitive abilities, and confidence in sketching. Quantitative assessments showed significant improvements in 2D and 3D, drawing confidence and interest among the experimental group. Complementing these findings, qualitative interviews revealed that students found the tool intuitive, engaging, and supportive of their transition to advanced design software such as SolidWorks™ and AutoCAD™.

Despite some usability challenges and integration issues, students consistently viewed the tool as a valuable learning resource that reinforced hands-on activities and improved learning outcomes. In particular, the combination of digital interaction and physical modeling appeared to enhance understanding of engineering drawing principles.

Importantly, the skills fostered through Spatial Vis™ extend beyond classroom applications. Enhanced spatial reasoning and sketching capabilities have direct implications for real-world problem-solving, design iteration, and industry-readiness—especially in fields that rely on precise visualization and technical communication.

Future research could explore longitudinal studies to assess long-term impacts and extend the tool's application across diverse institutions to evaluate its broader effectiveness. Addressing these gaps would provide deeper insights into the role of spatial visualization tools in STEM education and their potential to bridge academic learning with professional demands.

References

[1] S. A. Sorby, "Developing 3D spatial skills for engineering students," *Australasian Journal of Engineering Education*, vol. 13, no. 1, 2007, doi: 10.1080/22054952.2007.11463998.

[2] G. Raju and S. Sorby, "The Role of Spatial Skills and Sketching in Engineering Design Problem Solving," in *ASEE Annual Conference & Exposition*, Portland, Oregon, USA, June 23-26, 2024, doi: 10.18260/1-2--48133

[3] R. Porat and C. Ceobanu, "The Role of Spatial Ability in Academic Success: The Impact of the Integrated Hybrid Training Program in Architecture and Engineering Higher Education," *Educ Sci (Basel)*, vol. 14, no. 11, 2024, doi: 10.3390/educsci14111237.

[4] S. Sorby, E. Nevin, A. Behan, E. Mageean, and S. Sheridan, "Spatial skills as predictors of success in first-year engineering," in *Proceedings 44th Frontiers in Education Conference, FIE*, Madrid, Spain, October 22- 25, 2014. doi: 10.1109/FIE.2014.7044005.

[5] G. Duffy, S. Sorby, and B. Bowe, "An investigation of the role of spatial ability in representing and solving word problems among engineering students," *Journal of Engineering Education*, vol. 109, no. 3, 2020, doi: 10.1002/jee.20349.

[6] T. Branoff, J. Mohammed, and J. Brown, "The Role of Spatial Visualization Ability in Course Outcomes and Student Retention within Technology Programs," *Journal for Geometry and Graphics*, vol. 26, no. 1, pp.159-170, 2022.

[7] J. Šafranj and J. Zivlak, "Spatial-visual intelligence in teaching students of engineering," *Research in Pedagogy*, vol. 8, no. 2, 2018, doi: 10.17810/2015.72.

[8] P. Katsio-Loudis and M. Jones, "Using computer-aided design software and 3D printers to improve spatial visualization," *Technology and Engineering Teacher*, vol. 74, no. 8, 2015.

[9] Q. Dunsworth and D. Q. Lewis, "A Targeted Approach to Improving Spatial Visualization Skills of First-Year Engineering Students," in *ASEE Annual Conference & Exposition*, Portland, Oregon, , USA, June 23-26, 2024.

[10] O. Boxer, "The Elephant in the Room: Impact of Visual-Spatial Deficits in Children with Learning Disabilities and Why It Goes Untreated," *Help Letter*, Sherman Oaks, California, pp. 9–13, 2019. [Online], Available: The Elephant In The Room: Impact Of Visual-Spatial Deficits In Children With Learning Disabilities And Why It Goes Untreated — Insight Collective, [Accessed: Apr. 25, 2025]

[11] A. E. Margolis *et al.*, "Estimated Prevalence of Nonverbal Learning Disability Among North American Children and Adolescents," *JAMA Netw Open*, vol. 3, no. 4, Apr. 2020, doi: 10.1001/jamanetworkopen.2020.2551.

[12] W. Yang, H. Liu, N. Chen, P. Xu, and X. Lin, "Is Early Spatial Skills Training Effective? A Meta-Analysis," 2020. doi: 10.3389/fpsyg.2020.01938.

[13] N. Seery, J. Buckley, B. Bowe, and D. Carthy, "Spatial skills in education: A national study," in *33rd International Manufacturing Conference*, University of Limerick, Ireland, 2016.

[14] eGrove Education., “Spatial Vis,” 2024,[0nline], Available: *https://egrove.education/*. [Accessed: Apr. 25, 2025]

[15] N. Delson and L. Van Den Einde, “Sketching, assessment, and persistence in spatial visualization training on a touchscreen,” in *ASEE Annual Conference and Exposition, Conference Proceedings*, Salt Lake City, Utah, USA, June 23-27, 2018. doi: 10.18260/1-2--30968.

[16] J. W. Creswell and V. L. P. Clark, *Designing and Conducting Mixed Methods Research*. Singapore: SAGE Publications, Inc., 2017.

[17] S. Y. Yoon, “Psychometric properties of the Revised Purdue Spatial Visualization Tests: Visualization of Rotations (The Revised PSVT:R,” Purdue University, West Lafayette, 2011.