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Personalized Pathways to Proficiency: Evaluating Canvas Mastery Path for Spatial Visualization Development in First-Year Engineering

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Abstract

This evidence-based practice paper focuses on the unique application of Canvas Mastery Paths to help provide individualized learning support to first-year engineering students in the development of their spatial visualization skills. This work represents the first steps of a two-year effort aimed at replacing a traditional, standalone course designed to develop spatial visualization skills, by incorporating the materials into a common first-year engineering program. The primary objective of these first steps is to determine if the Mastery Paths, when tested separately, can achieve spatial visualization gains comparable to or exceeding the original instructional formats in the standalone spatial visualization development course and first-year engineering course.

The intervention employed Canvas Mastery Paths in five key modules in both the standalone spatial visualization development course and the first-year engineering course: Isometric Drawing, Orthographic Projection, Inclined and Curved Surfaces, Single-Axis Rotations, Multi-Axis Rotations. In both courses, the Mastery Paths began with an initial assessment and, based on a predefined threshold, the Mastery Path automatically directed low-scoring students to specialized support material before moving onto additional practice and assignments. While the high-scoring students were shown the support materials, they were allowed to skip the material, and were able to move directly to additional practice and assignments.

This quasi-experimental study evaluates the efficacy of the component Mastery Path interventions across a first-year engineering course during the 2024-25 academic year, comparing student gains, measured using the Purdue Spatial Visualization Test: Rotations (PSVT:R), to those observed in prior offerings of the courses using traditional instruction. We expect the Mastery Paths to result in similar gains to those observed using traditional course materials. If this is the case, we can confidently integrate the Mastery Path materials into a single adaptive system to provide individualized support to all students, and remove the standalone spatial visualization skills development course for the 2025-26 academic year.

Introduction/Background

Spatial visualization skills are critical for many scientific and technical fields such as engineering [1], [2], [3] as well as a strong indicator of success in course grades both inside and outside of engineering [4]. It is also important to develop these foundational skills early in the undergraduate curriculum as “students with poorly developed spatial skills are at a disadvantage in their ability to succeed in engineering graphics courses” [5]. These courses are often early in the undergraduate engineers' curriculum, which may negatively impact a students’ self efficacy for engineering [6]. This may be particularly important to women, who historically score lower in these areas than men [5], [7], [8], [9], [10]. Studies have shown, however, that students who have lower spatial skills entering college, but receive training to improve their spatial skills during their first year, show higher grades in their engineering and math courses as well as higher retention rates than students who did not receive this training [7], [10].

The first year of engineering study at Michigan Technological University consists of two engineering courses: ENG1101 and ENG1102. As spatial visualization skills are an important skill for engineering students, we identify students who would benefit from additional training in this area using the Purdue Spatial Visualization Test: Rotations (PSVT:R) [11] given during their new-student orientation. From 1993 - 2008, those students had the option of enrolling in a standalone spatial course (ENG-SV) that is taken concurrently with their first-semester engineering course (as shown in Figure 1 below) in preparation for their second-semester engineering course, where this material is reinforced and utilized for 3D modeling applications. From 2009 onward, this course was required for students to aid in the development of their spatial visualization ability [10].

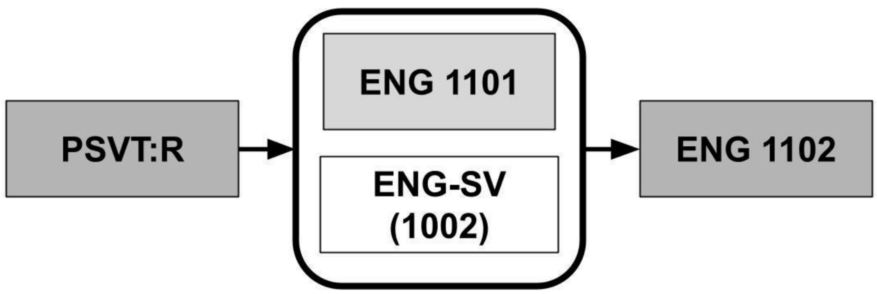

Figure 1. First-Year Evaluation and Instruction in Spatial Visualization

Prior to Fall 2023, the curriculum in our spatial visualization course (ENG-SV) consisted of ten topic modules: surfaces and solids of revolution, combining solid objects, isometric sketching of normal surfaces, orthographic drawings of normal surfaces, isometric and orthographic sketching of inclined and curved surfaces, flat patterns, rotations about a single axis, rotations about two or more axes, object reflections and symmetry, and cutting planes and cross sections [12], [13]. These ten modules all contained some lecture material, software tutorials, multiple-choice questions, hand-sketching pages, and exams. These materials were primarily completed during the 80-minute class periods with guidance from the course instructor. In the Spring of 2023, the course moved to a flipped model with some introductory and initial assessment of the material being completed by the students prior to the course session, and the remaining module materials being completed in the now 50-minute class sessions. In our second-semester course, ENG1102, students complete additional advanced practice on isometric and oblique sketching, rotations about single and two or more axes, and orthographic projections with normal, inclined, and curved surfaces.

While this path has shown to benefit first-year engineering students in our program [5], [10], there are some concerns or opportunities for improvement. First, a supplementary course may have the perception of being remedial and reduce a student's engineering self-efficacy [14]. Additionally, this is an extra one-credit that students need to purchase for their engineering degree. Some students score higher than the cutoff threshold for enrollment into our spatial visualization course who may also benefit from additional instruction in this area and are not receiving support. Finally, while the PSVT-R test focuses solely on rotations, this may not serve as a reliable measure for other spatial skills, such as orthographic projection or sectioning tasks

[15][16]. With these considerations in mind, the first-year engineering program decided to evaluate an individualized competency-based pathway for spatial visualization education. The goals of this path were to a) clearly identify all students who need help with a specific topic and provide them with assistance to build their skills in these areas, b) to reinforce these skills in students who do not need remediation, and c) provide these resources in a way that did not require the addition of a separate course.

To that end, our first-year engineering team began the lengthy process of transitioning this stand-alone course into the existing first-year engineering course framework. Our first step in this process was to create and evaluate the efficacy of these individualized paths. We started by working in the current spatial visualization course. Canvas is the learning management system used at Michigan Tech and we have already transitioned the spatial visualization curriculum to utilize modules in Canvas. This made the transition to an individualized path a little more simpler as we could evaluate and customize a path based on each skill separately using Canvas Mastery Paths. Canvas Mastery Paths are designed for the instructor to tailor education based on initial test results, graded assignments, or graded discussions [17]. Once the initial assessment is graded, the remaining materials in the Mastery Path will be opened for the student and they will only see the materials assigned to them.

In our spatial visualization course, we created Canvas Mastery Paths in five key modules: Isometric Drawing, Orthographic Projection with Normal Surfaces, Orthographic Projection with Inclined and Curved Surfaces, Single-Axis Rotations, Multi-Axis Rotations. An example Mastery Path example for our spatial visualization course is shown below in Figure 2. The students begin with some background material (reading and video) on the selected topic. After reviewing these materials, the students take an initial self-assessment. We used a threshold of 80% on this initial assessment to point the students down an instructional path. The Mastery Paths automatically directed students who scored below this threshold to complete Developing Spatial Thinking Software Modules before moving onto additional practice (multiple choice questions, hand sketching practice), and a sketching assignment. Students who scored at this threshold or above were shown the support materials, but were not required to complete them before moving onto additional practice (multiple choice questions, hand sketching practice), and a sketching assignment.

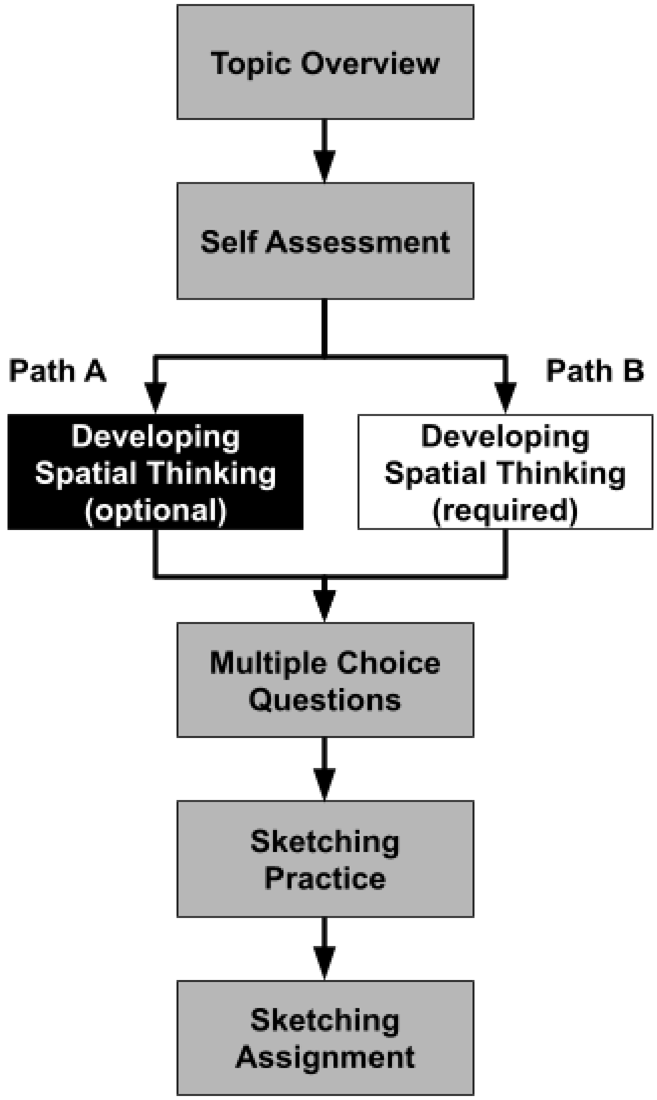

Figure 2. Example Canvas Mastery Paths for Spatial Visualization Pilot 1

The second study (Pilot 2) was conducted during Spring 2025 in our second engineering course (ENG1102). In this course, we brought in the introductory materials, self-assessment, Developing Spatial Thinking Software and multiple choice questions from the spatial visualization course and combined them with the current sketching practice and assignments from ENG1102. This can be shown in Figure 3 below.

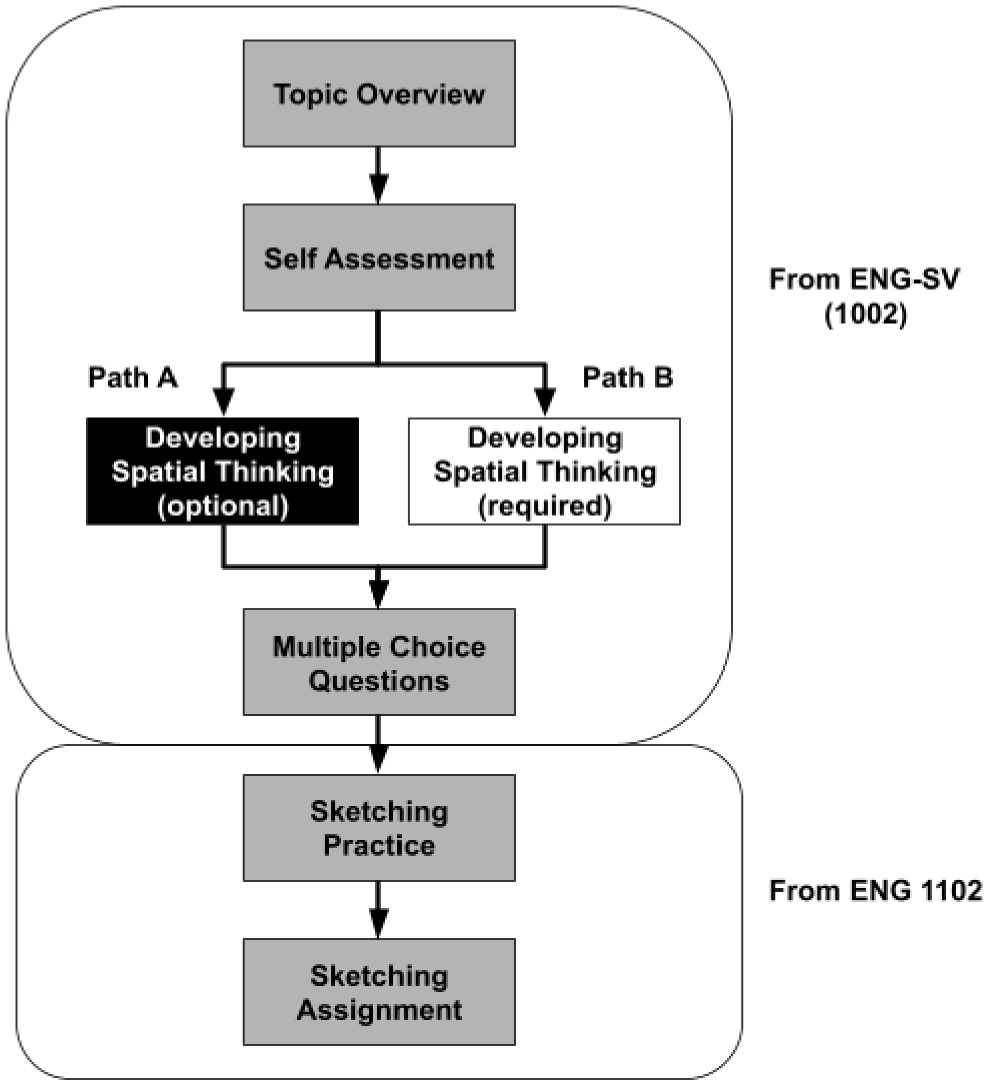

Figure 3. Example Canvas Mastery Paths for Spatial Visualization Pilot 2

These pilot studies were used to determine if the Canvas Mastery Paths could be used to create an effective customized learning path. We expect the Mastery Paths will result in similar gains to those observed using traditional course materials. If this is the case, we can confidently integrate the Mastery Path materials into a single adaptive system to provide individualized support to all students, and remove the standalone spatial visualization skills development course for the 2025-26 academic year.

The final proposed model can be shown in Figure 4 below. In this model, the spatial visualization modules from the standalone spatial course, would be incorporated into the first-year engineering courses (ENG1101 and ENG1102). Isometric Drawing, Single-Axis Rotations, and Multi-Axis Rotations modules would be included into ENG1101, while the two Orthographic Projection modules (Normal and Inclined and Curved Surfaces) would be included in ENG1102. For each module, the students would first review the introductory material and complete the self-assessment. Those students who score at or above the 80% threshold would be directed to Path A where they would complete the typical ENG1102 material for that topic. Those who test below the 80% threshold would be directed to Path B, which would contain the spatial visualization content (ENG-SV) on that topic.

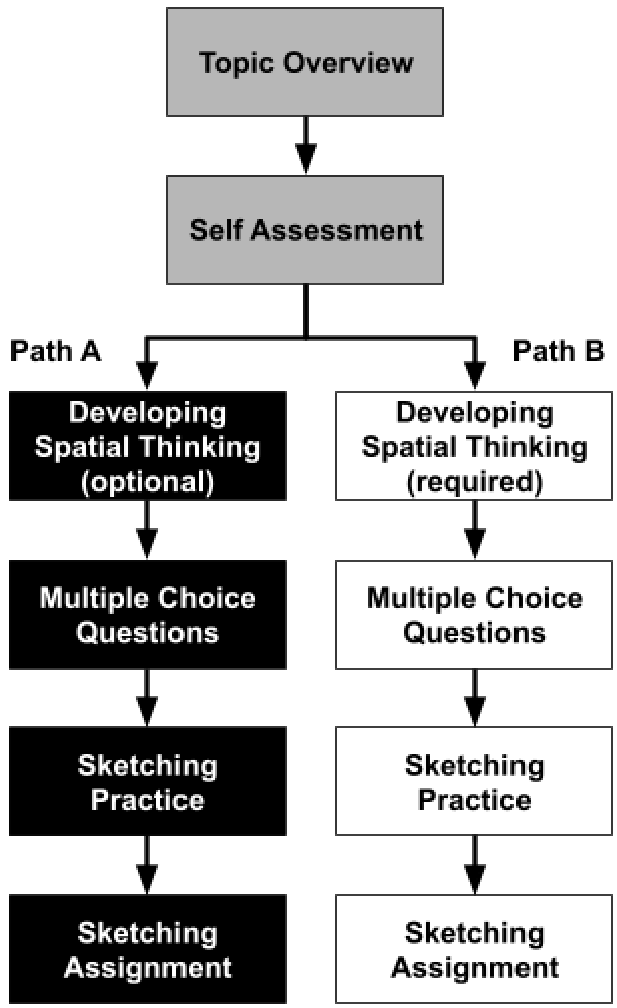

Figure 4. Final Proposed Integrated System for First-Year Engineering with Spatial Content

Methods

As mentioned previously, this initial study was used to determine if the Canvas Mastery Paths could be used to create an effective customized learning path. To do that, we needed to determine if the new mastery module (pilot) approach was comparable to or improved student's spatial mastery compared to the previous year's traditional instruction. To do this, PSVT scores were compared across different years of students. Historical data exists as first-year engineering students were required to take the Purdue Spatial Visualization Test: Rotations (PSVT:R) at multiple points during their instruction during previous years in this program.

For the purposes of classifying student scores there are four categories of student scores for the PSVT:R. These categories are failing, marginally passing, passing, and highly passing [6]. The PSVT:R test consists of 30 questions with each being equally weighted at one point. Students who scored below 19 points are categorized as failing, students who scored between 19 and 21 are considered marginally passing, students who scored between a 22 and a 27 are considered passing, and students scoring 28 or above are considered highly passing. These categories allow for specific groups of student scores to be compared and historically determined if an additional traditional instruction was needed for students.

Students who were categorized as "failing" completed the activity three times during their first-year engineering courses. The first time was prior to classes starting, the second time after the completion of the spatial visualization course (ENG-SV), and a final time after the completion of their final first-year engineering course (ENG1102). Students who were categorized as "marginally passing", "passing", or "highly passing" took the PSVT:R twice during their first-year engineering courses. These times were at the beginning of the ENG1101 course and at the end of their first-year engineering courses (ENG1102). PSVT:R tests that are conducted at the beginning of the year are referred to as "Pre-tests" and those that are conducted at the end of the year are referred to as "Post-tests".

The 2024-2025 academic year was the first year using the mastery module approach to spatial learning and will be compared to a prior academic year for the pilot tests. For Pilot 1, to determine the efficacy of the Canvas Mastery Paths in the Spatial development course (ENG-SV), our years for comparison for this pilot were Fall 2023 and Fall 2024. For Pilot 2, we will use the 2021-22 and 2024-25 academic years. It is critical to note that all of the academic years that were chosen had classes taught fully in person, and there is no virtual learning data included for this analysis. Both of the chosen years used the same traditional approach to teaching the material. Statistical tests will be used to verify that each year's pre-test and post-test data has a statistically significant improvement on scores within the same academic year, that the first year pre-test data has no statistically significant difference between academic years, and that there is no statistically significant decrease in student scores between post-tests in different academic years.

All first-year engineering students completed the PSVT:R Pre-Test, but some groups of students were not eligible to be included in the analysis of the data for Pilot 2. The first group of students are those who were enrolled in our spatial mastery course in Fall 2024 (these are evaluated in Pilot 1). These students had additional instruction beyond what is included in the spatial mastery modulus and determining their score increase would not be representative of just the mastery module approach. The second group of students are those who did not take the traditional first-year engineering courses back to back. These are students who may have taken ENG 1101, but then waited a semester to take ENG 1102 or students who did not have ENG 1102 scores. Since these students would have been enrolled in two different approaches to teaching this material they are also excluded from the data set.

Student scores within the academic year were recorded as pre and post tests during the semester the PSVT:R was taken. These scores were then matched together so that each student who completed both had both test scores. For Pilot 1, the scores used were the initial score during orientation and the final score at the end of the spatial visualization course. For Pilot 2, the pre-test scores were the initial scores during orientation and post-test scores were those at the end of ENG1102. Again, students who were in our spatial mastery course category (ENG-SV) were removed from the Pilot 2 data set.

To accomplish the statistical analysis, two different methods will be used for the data. Pre-tests and post-tests for the same academic year will use a paired t-test to determine if there is a statistically significant difference between scores. For pre-tests and post-tests being compared to their equivalents in another academic year, Welch's t-test will be used.

Results and Analysis

Pilot 1 - Canvas Mastery Paths in Spatial Visualization Development Course

To determine if the Canvas Mastery Paths approach used in the spatial visualization course results in similar gains, this approach was piloted in the spatial visualization development course (ENG-SV). Students in this course scored a failing grade on the PSVT:R and were required to have additional instruction on spatial mastery skills. This group of students in the 'failing' category were the ideal group to trial this approach as the Canvas mastery module approach should cater better to their individual needs.

Students in this group take the PSVT:R an additional time after completing ENG-SV, before moving on to ENG1102. To determine if the mastery module approach would be a valuable approach to trial with all first-year engineering students, the scores from Fall of 2024 using the new mastery module approach are compared against the traditional method used in Fall of 2023. These two data sets were compared against each other using a Welch's t-test to accommodate for different sizes in the classes between years (Table 1).

Table 1. Statistics of Welch's T-test on Comparing Fall 2023 and Fall 2024 Post Spatial Visualization Development Course (ENG-SV) PSVT:R Scores

Term	Result
T-Statistic	2.73
Degrees of Freedom	196
Standard Deviation	5.057
Upper Confidence Bound	-0.571
Lower Confidence Bound	-3.536
Null Hypothesis	Rejected

The result of this analysis is that there was a statistically significant improvement in student scores when moving to the new piloted Canvas mastery approach compared to the traditional instruction approach. With the Canvas Mastery Paths implemented in Fall 2024 ENG-SV resulting in as good or better gains on the PSVT:R than in the Fall 2023 offering of ENG-SV, the decision was made to pilot the Mastery Paths approach for all of the first-year engineering students.

Pilot 2 - Canvas Mastery Paths in First-Year Engineering Courses

After analyzing the student scores from the new mastery module approach in the First-Year Engineering Courses (ENG1101 and ENG1102) during the 2024-2025 academic year and comparing them to student scores in the 2021-2022 academic years, it was determined that the new mastery module approach is at least comparable to the previous methods as there is no statistical difference between post test results for students. It was also verified that there was no statistically significant difference between Pre-Test scores.

First, it was determined that the Pre-Test and Post-Test scores for the 2024-2025 academic year had a statistically significant increase. After removing students who took ENG-SV and students who did not take both the Pre-Test and Post-Test, the scores were plotted to visually inspect (Figure 4) (Figure 5). Visual inspection of the data confirms that it is not normally distributed, the data is left-leaning, and that a paired t-test should be used to determine statistical significance.

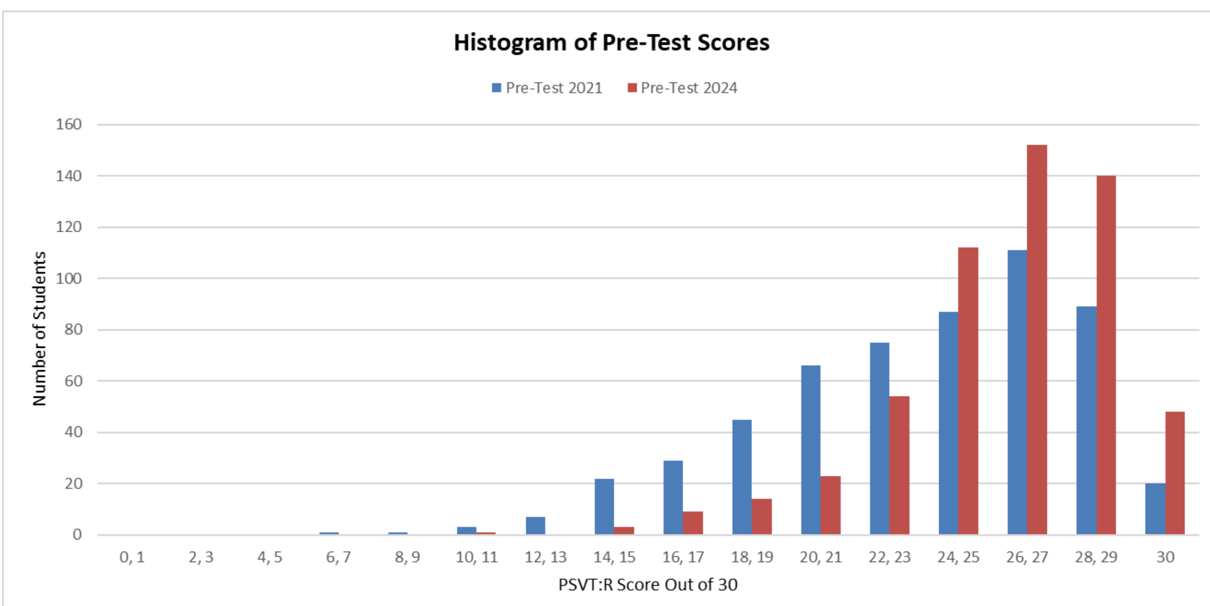

Figure 4. Histogram of Pre-Test Results for 2021 and 2024

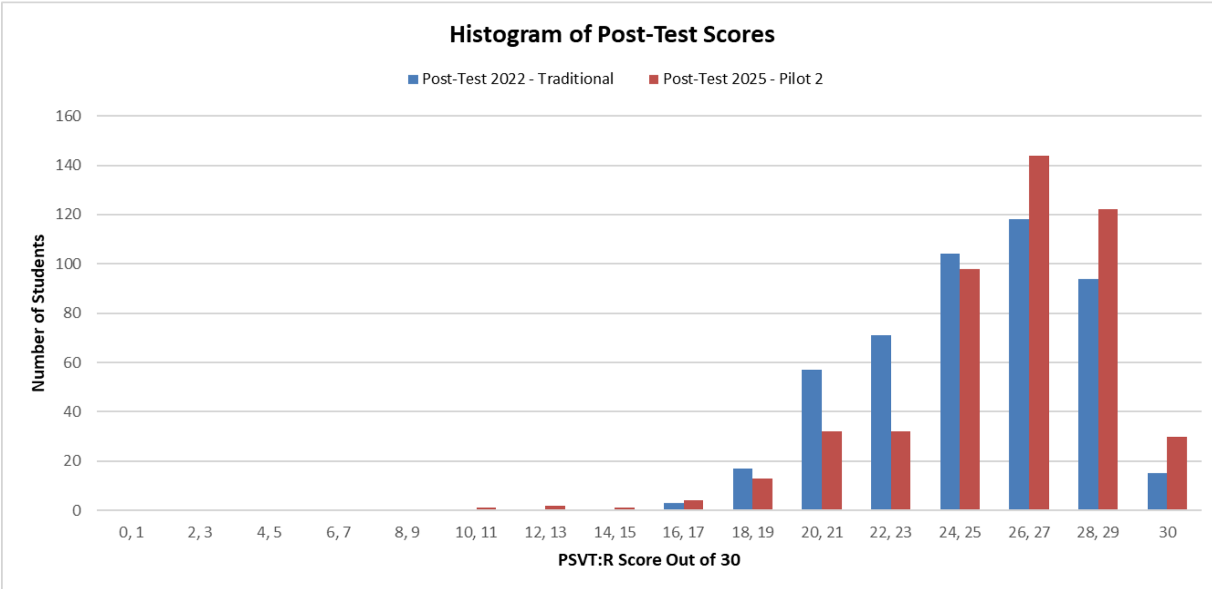

Figure 4. Histogram of Post-Test Results for 2022 and 2025

A paired t-test was conducted on the pre-test and post-test data without our spatial mastery course students and resulted in a rejection of the null hypothesis (Table 2). This result is consistent with what was expected. Students received instruction on and completed spatial mastery assignments. After practicing their skills, taking the same assessment should result in a higher score.

Table 2. Test Statistics of Paired t-test on 24-25 PSVT:R Scores

Term	Result
T-Statistic	5.9
Number of Samples (*n*)	479
Degrees of Freedom	478
Standard Deviation	3.02
Alpha	0.05
Null Hypothesis	Rejection

In addition to the paired t-test, the quartile values were recorded for both the pre-test and post-test scores (Table 3). These quartile results are useful as they allow the data collected in the 2024-2025 data set to be compared with historical research on the impact of spatial mastery scores.

Table 3. Quartile Results of pre-test and post-test scores for 2024-2025

Quartile Values	Q1	Q2	Q3	Q4
Pre-Test	0-21	22-24	25-27	28-30
Post-Test	0-23	24-26	27-28	29-30
Historical	0-21	22-24	25-27	28-30

Finally, the pre-test and post-test scores were categorized into the four passing and failure categories historically used to place students into our spatial mastery course. The categorization of data with and without the our spatial mastery course students was conducted (Table 4). This result is not unexpected as the students who were in the failing group during 2024 would have been placed into our spatial visualization course during the fall and would not be included as they had additional instruction beyond the Mastery Paths.

Table 4. Pass/Fail Results of pre-test and post-test scores for 2024-2025

Test	Failing	Marginally Passing	Passing	Highly Passing
2024 Pre-Test	3	74	293	109
2025 Post-Test	12	41	274	152

With the pre- and post-test scores verified to be statistically different for 2024-2025 scores, the scores from 2021-2022 using the previous instruction model were evaluated. First, the pre-tests and post-test scores were verified to have a statistical increase in score. This was done using the same method as the 2024-2025 student scores (Table 5). After conducting a paired t-test on the 2021-2022 pre- and post-tests, it was determined that the null hypothesis is rejected. This means that there is a statistically significant increase between the scores from the pre-test to the post-test.

Table 5. Statistics of Paired T-test on 21-22 PSVT:R Scores

Term	Result
T-Statistic	14.98
Number of Samples (n)	557
Degrees of Freedom	556
Standard Deviation	3.86
Alpha	0.05
Null Hypothesis	Rejection

These student scores were categorized in the same way as the 2024-2025 test scores (Table 6). This categorization tracks with the expected data and will be missing many of the failing student scores as they will have completed our spatial mastery course, making their scores invalid for comparison with the students from 24-25 who did not take our spatial master course.

Table 6. Pass/Fail Results of pre-test and post-test scores for 2021-2022

Test	Failing	Marginally Passing	Passing	Highly Passing
2021 Pre-Test	90	85	273	109
2022 Post-Test	17	33	319	188

After verifying that there were statistically significant increases in student scores using the traditional style of instruction, the results from the pre-tests in 2021 and 2025 were compared. To accomplish this comparison, a Welch's t-test was used to compare the scores as there are not equal amounts of samples to be compared (Table 7). Comparison of the pre-test results yielded a rejection of the null hypothesis, meaning that the pre-test scores have a statistically significant difference between them.

After determining this, Welch's t-test was rerun under the assumption that the two data sets had differing means (Table 8). After completing this statistical analysis, the null hypothesis was rejected again for the data set. The two sets of pre-test scores are not equivalent and are therefore covariables for this study. Due to the nature of the research question focusing on the impact of mastery module approaches on student scores, this difference should not impact the results in a way that affects the outcome of the study.

Finally, the post-test scores were compared from 2022 to 2025. These scores were compared using a Welch's t-test in order to accurately determine the statistical difference between the test scores (Table 9). The results of this test is that the null hypothesis failed to be rejected, meaning that there is no statistically significant difference between the post-test results for 2021 and 2025. This result confirms that overall, the Canvas Mastery Paths method of instruction is at least as good as the traditional method overall.

Table 7. Statistics of Welch's t-test on 21 and 24 Pre-Test PSVT:R Scores

Term	Result
T-Statistic	-6.39
Degrees of Freedom	1034
Standard Deviation	3.88
Upper Confidence Bound	-1.068
Lower Confidence Bound	-2.015
Null Hypothesis	Rejection

Table 8. Statistics of Welch's t-test on 21 and 24 Pre-Test PSVT:R Scores Assuming Unequal Means

Term	Result
T-Statistic	-6.57
Degrees of Freedom	975.89
Standard Deviation	4.497, 2.997
Upper Confidence Bound	-1.081
Lower Confidence Bound	-2.002
Null Hypothesis	Rejection

This result confirms that this new method of teaching spatial visualization skills is effective and can be used to build spatial visualization skills in first-year engineering students. It also confirms that the longer term plan of implementing the Canvas Mastery Paths across the first-year engineering curriculum to replace the special spatial mastery class (ENG-SV) should result in the same positive effect on student scores as the traditional method.

Table 9. Statistics of Welch's T-test on 22 and 25 Post-Test PSVT:R Scores

Term	Result
T-Statistic	0.48
Degrees of Freedom	1034
Standard Deviation	3.13
Upper Confidence Bound	0.475
Lower Confidence Bound	-0.290
Null Hypothesis	Fail to Reject

Conclusions

This quasi-experimental study evaluates the efficacy of the component Mastery Path interventions across a first-year engineering course during the 2024-25 academic year, comparing student gains, measured using the Purdue Spatial Visualization Test: Rotations (PSVT:R), to those observed in prior offerings of the courses using traditional instruction. In our first pilot, we created the Canvas Mastery Paths for five learning modules and compared pre-and post-PSVT:R test scores in our Spatial Visualization Skill Development course (ENG-SV). The results indicated a statistically significant improvement in student scores using the Canvas Mastery Modules and the decision was made to implement the Mastery Paths into the second engineering course in Spring 2025 (ENG1102).

In our second pilot, we compared pre-and post-PSVT:R test scores for the 2021-22 and 2024-25 academic years for only those students not enrolled in the Spatial Visualization Skills Development course (ENG-SV). For this pilot, we found no statistically significant differences between instruction delivered using the Canvas Mastery Paths and the traditional course material delivery methods.

As a result, we feel confident in utilizing these Canvas Mastery Paths to deliver individualized instruction to students. Beginning in Fall 2025, for each of the spatial visualization modules, all students will complete an initial assessment and based on their performance will be directed to the support the support material from the Spatial Visualization Skills Development course (ENG-SV) materials if they score below the threshold, or they will be directed to the more advanced first-year engineering course materials (from ENG1102) if they score above the threshold. This will be incorporated throughout the first-year engineering program with three of the course modules being implemented in the first semester course (ENG1101) and the remaining two modules implemented in ENG1102 during the second semester.

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