

UNIVERSITY OF OKLAHOMA GRADUATE COLLEGE

INDICATOR OF SUCCESS IN ENGINEERING

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

Degree of

MASTER OF SCIENCE

By

Joyeshree Biswas

Norman, Oklahoma

2024

INDICATOR OF SUCCESS IN ENGINEERING

A THESIS APPROVED FOR THE
SCHOOL OF INDUSTRIAL AND SYSTEMS ENGINEERING

BY THE COMMITTEE CONSISTING OF

Dr. Doyle Dodd

Dr. Janet K. Allen

Dr. Christopher Dalton

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Abstract

This study investigates the relationship between spatial skills, mathematics skills, and academic performance in sophomore-level engineering statics courses. A total of 102 students enrolled in a Sophomore-level statics course participated in an IRB-approved research study at the University of Oklahoma, with spatial and math skills assessed through pre-tests and post-tests. Analysis of the results revealed no significant correlation between spatial skills and course grades, indicating that spatial abilities may not be a major predictor of success in a statics course. However, a significant improvement in spatial skills was observed from pre-test to post-test, suggesting that the instructional methods of the course effectively enhanced spatial reasoning abilities. Gender differences were noted, with male students outperforming female students in spatial skills, highlighting the need for targeted interventions. Familiarity with CAD courses prior to college also correlated with higher spatial skills, underscoring the importance of early exposure to spatially oriented learning. While a moderate correlation was found between spatial and mathematics skills, neither skill set was shown to be a strong predictor of academic performance. These findings call for a nuanced understanding of the factors influencing student success in engineering, other factors beyond spatial reasoning and mathematical skills may play a role in student success in a sophomore-level engineering course.

Introduction

Spatial skills are a collection of connected skills related to the elicitation, construction and manipulation of internal mental models. Associated tasks, including mentally rotating shapes or objects, constructing 3D structures from 2D patterns and identifying cues from obscured environments, were given the name 'spatial skills' (Parkinson & Cutts, 2020). Harris et al., 2020, describes three common types of spatial skills, namely Mental rotation, Spatial visualization and Spatial orientation. Mental rotation refers to the ability to imagine a rotation of an intact 2D shape or 3D object. Spatial visualization refers to the ability to imagine complex, multi-step spatial transformations within objects. It is measured by tasks that involve imagining object-based transformations such as paper folding, or net to solid conversions. Spatial orientation is the ability to imagine a different perspective, while either navigating through space or imagining an alternate view of a stationary object.

Spatial skills are essential for success in stem fields such as Engineering, Chemistry, Computer Science, Mathematics, Physics, Medicine, Dentistry, and many other fields. Research has consistently demonstrated that students with stronger spatial skills tend to achieve greater success in stem disciplines and exhibit higher retention rates in college (De Rosa and Fontaine, 2019). Many studies have been conducted focusing on improving spatial skills, while others have explored the various factors influencing these abilities.

Numerous studies have explored effective methods for improving spatial skills among students, particularly given their importance in engineering success. Researchers have developed courses designed to enhance these skills, evaluating the impact of these programs on students' spatial abilities. For instance, De Rosa and Fontaine (2019) conducted a study that showed a workshop combined with a graphics class significantly improved students' spatial skill. Similarly, Dimitriu, D. G., & Dimitriu, D. C. (2020) proposed a more challenging, new method for enhancing 3D visualization skills. They developed and evaluated a technique over a nine-year period, which involves counting blocks to create an object from three projected views. After training with this approach, a qualitative survey revealed that most students provided positive feedback about the method.

Additionally, Charlesworth et al., 2005, created nine multimedia software and workbook modules aimed at developing spatial skills. They examined whether these tools could benefit students in non-engineering majors and also looked into gender differences in learning styles. Their findings indicated that both the multimedia software and workbook modules effectively enhanced the spatial skills of non-engineering students, with those using the workbook performing better than those using the software. Notably, no gender differences in learning outcomes were observed.

Finally, Viswanathan et al., 2020, developed a course called SAVE to enhance spatial skills. Their evaluation compared the spatial skill scores of students in the SAVE course with those in an existing program, revealing that SAVE participants achieved higher scores.

Researchers have explored various tools and techniques to enhance spatial skills in learners. LeBow et al., 2018, tested the effectiveness of 3D printed blocks for improving spatial

abilities, finding significant improvements as a result. Dominguez et al., 2013, examined whether teaching with virtual objects is more effective than using physical ones. They utilized three digital tools—Augmented Reality (AR), Virtual Reality (VR), and PDF (Portable Document Format)—and discovered that students preferred AR over VR and PDF, showing greater cooperation and motivation when using virtual objects in classroom settings compared to physical objects.

Di and Zheng (2022) reviewed journals to assess the impact of virtual technologies on students' spatial abilities, concluding that these technologies have a moderate effect on skill development. Azzam, I. et al., 2024, investigated how Mixed Reality (MR) can serve as a pedagogical tool to enhance students' spatial visualization skills, with findings indicating that MR has the potential to improve spatial abilities.

Additionally, A studies have focused on improving spatial skills in school students, emphasizing the importance of early education in this area. Šafhalter, A. (2020) conducted a study on the effects of using the SketchUp computer program for engineering 3D modeling on students' spatial thinking and visualization. The results demonstrated that incorporating spatial modeling with SketchUp in early technology education significantly enhances children's spatial visualization skills, regardless of their prior experience or academic performance in Technics and Technology.

Numerous studies have explored the factors that enhance spatial visualization skills. Schwartz et al., 2006, conducted research to identify how students process 3D models. They videotaped students as they solved problems during tests to analyze their strategies, identifying key aspects of problem-solving that contributed to success.

Sorby and Veurink (2010) conducted a study on incoming first-year students at Michigan Tech, in which they administered a pretest. Those who did not pass the test were required to take a course aimed at developing their 3D spatial skills. The results of the study indicated that the spatial skills of incoming students have been improving over time, and also found that playing video games on computers can contribute to enhancing visualization skills.

Margulieux, L. E. (2020) proposed the Spatial Encoding Strategy (SpES) theory to explain the cognitive mechanisms linking spatial skills with STEM achievement in the article "Spatial Encoding Strategy Theory: The Relationship Between Spatial Skill and STEM Achievement." The article supports SpES theory by reviewing research from STEM education, learning sciences, and psychology, providing strong post hoc explanations for the findings and aligning with neuroscience models related to brain function.

Rahmawati et al., 2021, investigated students' spatial abilities using a 3D virtual representation in the context of molecular geometry. They employed a qualitative methodology to analyze how students' spatial skills developed during learning activities. The findings revealed that while students exhibited low spatial orientation abilities, they demonstrated stronger skills in spatial relationships that involved mental manipulation and rotation of 2D or 3D objects.

Alvarez-Vargas et al., 2020, examined gender differences in spatial ability, proposing that spatial anxiety—the fear experienced when engaging in tasks requiring spatial reasoning—might explain the relationship between gender and performance on mental rotation tests. Their research

found that mental rotation anxiety mediates the differences observed in mental rotation performance between sexes.

Bairaktarova et al., 2015, conducted a study to investigate whether life experiences had any correlation with spatial skills. Specifically, they examined the effects of playing video games, participating in sports, engaging in art and music, and working with hands-on spatial skills. The result shows that the individuals who played video games, participated in sports, engaged in art and music, and worked with their hands were more likely to have stronger spatial skills.

Several studies have explored the connection between spatial skills and mathematics. In a literature review by Hawes et al., 2022, on the relationship between spatial and mathematical skills, it was revealed that spatial training enhances individuals' spatial thinking and serves as an effective method for improving mathematical understanding and performance. They found a limited understanding of the underlying mechanisms that facilitate this transfer between spatial skills and mathematics.

Atit et al., 2020, researched whether spatial skills could be linked to students' motivation in mathematics. They collected measures of spatial skills and mathematics motivation from 1,056 seventh-grade students. The results suggested that both spatial skills and motivation significantly influence middle school students' math achievement.

Atit et al., 2021, later reviewed various articles to assess the strength of the relationship between spatial skills and mathematics. They identified a positive correlation between the two, but found no significant impact of gender or grade level on this association. Additionally, they noted that fluid reasoning and verbal skills mediated the relationship, yet a distinct connection between spatial and mathematical skills persisted.

Harris et al., 2020, investigated the roles of spatial orientation and gender in the relationship between spatial reasoning and mathematics. They examined three spatial reasoning constructs—mental rotation, spatial visualization, and spatial orientation—to understand their unique contributions to mathematics performance among females and males, as well as across different mathematical content areas (geometry, measurement, and number sense). Their findings highlighted the unique role of spatial orientation in the spatial-mathematics relationship and provided insights into gender differences in mathematical problem-solving related to spatial reasoning and mathematics content. Gender difference were found in spatial reasoning while no gender difference was found on performance of math.

Another area of study has focussed on the relationship between spatial skills and academic performance. Parkinson and Cutts (2020) studied the effects of spatial skills training in introductory computing courses. They provided an intervention for students with low spatial abilities, discovering that both spatial skills and assessment scores in computing improved following the course. Participants in the intervention made significant progress compared to their peers, indicating that spatial skills training can positively influence STEM fields such as engineering, mathematics, and physics.

In another study, Endres et al., 2021, investigated whether reading training or spatial training led to better programming outcomes. They found that participants who received reading

training showed greater improvements in programming skills than those who underwent standard spatial training.

Veurink and Hamlin (2011) explored the correlation between spatial skills and students' choice of major. They compared the spatial skills of freshman students majoring in mechanical engineering with those in environmental engineering, revealing that mechanical engineering students had higher spatial skills. This suggests that spatial skills may influence students' decisions regarding their engineering majors.

Serdar and deVries (2015) examined the relationship between spatial skills and performance in a technical drawing course, finding that spatial skills positively impacted learning. They also noted that gaming experience enhanced scores in technical drawing courses.

Tseng and Yang (2011) investigated the role of spatial skills in a mechanical engineering design course, where students designed robots to complete complex tasks. They found no correlation between spatial skills and the complexity of the robot designs.

Gurganus et al, 2018, discovered that students enrolled in both pre-engineering and math courses performed better than those taking only math courses. Lastly, Yue (2002) studied spatial skills across various educational levels and found that these skills generally improve with higher education. The researcher also examined the correlation between spatial skills and scores in two courses: CAD (Computer-Aided Design) and engineering graphics. While there was no significant correlation between spatial skills and CAD scores, a significant correlation was found between spatial skills and graphics scores.

Dong and El-Sayed (2011) assessed students' spatial skills, requiring those who scored low to enroll in a spatial development course. The researchers then evaluated these students' spatial skills before and after the modified Technical Graphical Communications (Freshman level) and statics engineering course (sophomore level course with a Technical Graphical Communications course prerequisite), finding that spatial skills before and after the modified Technical Graphical Communications did not change, although spatial skills of students in the statics course were better than the spatial skill scores of students in the Technical Graphical Communications course. They suggest their findings were affected by a lack of motivation in the students (not for course credit) and/or a lack of necessary time to fully conduct the assessments (students may have run out of time during one or more testing opportunities).

To summarize, the existing research has largely focused on developing and evaluating new methods for improving spatial skills and exploring factors related to spatial visualization skills. Some researchers have explored the contribution of spatial skills toward academic performance in specific courses; however, there has been no research to explore the effect of spatial skills on engineering success. This research aims to assess and evaluate the effect of spatial skills on engineering success. Additionally, this research will analyze a potential link between spatial skill and various factors influencing these abilities. The following sections consist of method, analysis and result, discussion and conclusion and future research section sections.

Method

A total of 102 students participated in this IRB-approved study. Participants were enrolled in one of three different Sophomore-level Engineering Statics sections at the University of Oklahoma. One of the statics classes, with 32 participants, was offered by the civil engineering department. The other two statics sections were offered by aerospace and mechanical engineering departments, each with 35 participants. Each of the three statics sections were instructed by a different professor. While there was some variation in the materials covered between the three course sections, the majority of material being covered was similar from section to section. Common statics topics such as drawing free body diagrams were covered in all three course sections. Each course extends 16 weeks. One was MWF for 50-minute periods, another was T/Th for 75 minutes and third one was MW for 75-minute periods.

The average age of participants is 20yrs with a standard deviation 1yr. Participants' spatial skills and mathematics skills were tested on the first day of class for the semester (pre-test) and in the final week of the semester (post-test). Pre- and post-spatial tests were conducted in all three statics sections, while the math pre- and post-tests were conducted in two classes.

The pre- and post-spatial skills tests each included 12 questions designed to assess spatial abilities. The first two questions of each spatial skills tests required participants to draw the top view, front view, and right view based on an isometric view, while the next ten questions asked them to create an isometric view from the top view, front view, and right view. The geometric shapes used in the spatial skill test looks like the jig and fixture shape at the mechanical machine shop. Participants were allotted 10 minutes to complete each of the two spatial tests. See Appendix A and B for the pre- and post-spatial skills tests. Mathematical skills were evaluated using geometric and trigonometric questionnaires, with the pre-test containing 5 questions and the post-test consisting of 7 questions. Participants had 7 minutes to finish the math test. See Appendix C and D for the pre- and post-math skills tests. A mobile stopwatch was used to time the tests, with participants completing the math test before moving on to the spatial test.

Spatial skill test questions are graded on a scale from 0 to 4, with the following guidelines:

- 0 for not answered
- 1 attempted but could not imagine the shape
- 2 partially imagine the shape
- 3 imagine the shape but a minor mistake such as scale, orientation
- 4 correctly define the shape

Math test questions are graded on a scale from 0 to 3, with the following guidelines:

- 0 not answered
- 1 attempted but wrong
- 2 partially correct
- 3 correct

A survey was conducted asking participants' age, gender, race, current major in college, name and location of their high school, size of their graduating class in high school, and the name of the final math course they took in high school to find any correlation of these factors with spatial skills. Participants were also asked whether they had previously ever taken any CAD/Drafting courses, art courses, and/or shop classes/industrial tech classes to investigate how those courses may have affected their spatial visualization skills. See Appendix E for the survey test questionnaires.

The Participants' ACT and SAT scores were gathered from the Open Records Office of the University of Oklahoma. ACT scores of 62 participants SAT scores of 34 participants were received. The ACT and SAT are the two most widely recognized standardized tests used in the college admissions process in the United States. The ACT is an assessment that tests students on their understanding of their high school curriculum and covers coursework in English, reading, math, and science. Each section is tested out of a score 36. The SAT, traditionally considered more of an aptitude test, includes only English, reading, and math; it does not have a science section. the math section of SAT is scored out of 800 and the reading and writing section is scored out of 800.

Microsoft Excel was used for the majority of data analysis, with R being used for additional analysis as well as data visualization.

Analysis and Results

Participants' spatial test scores were analyzed in relation to their course grades. Those who received a final course grade of A, B, or C were grouped as “passing” (A/B/C), while those who did not successfully pass the course (received D, F, or dropped the course) were grouped as “not finishing” (D/F/Drop). The spatial skills of these two groups were compared. Figure 1 presents a box plot of the spatial pre-test scores for both groups, with $n = 78$ participants in group A/B/C and $n = 17$ in group D/F/Drop. The mean spatial pre-test score for group A/B/C is 30.64, while for group D/F/Drop, it is 29.41. The normality of the spatial pre-test score data was assessed using the Shapiro-Wilk test, which yielded a p-value of 0.006066, indicating that the data are not normally distributed. The Mann-Whitney Wilcoxon revealed a p-value of 0.5567 ($> .05$), suggesting the spatial skills of these two groups of students did not significantly differ at the onset of the course. These results imply that spatial reasoning skills may not play a major role in the success or struggle of engineering students in this Sophomore-level statics course.

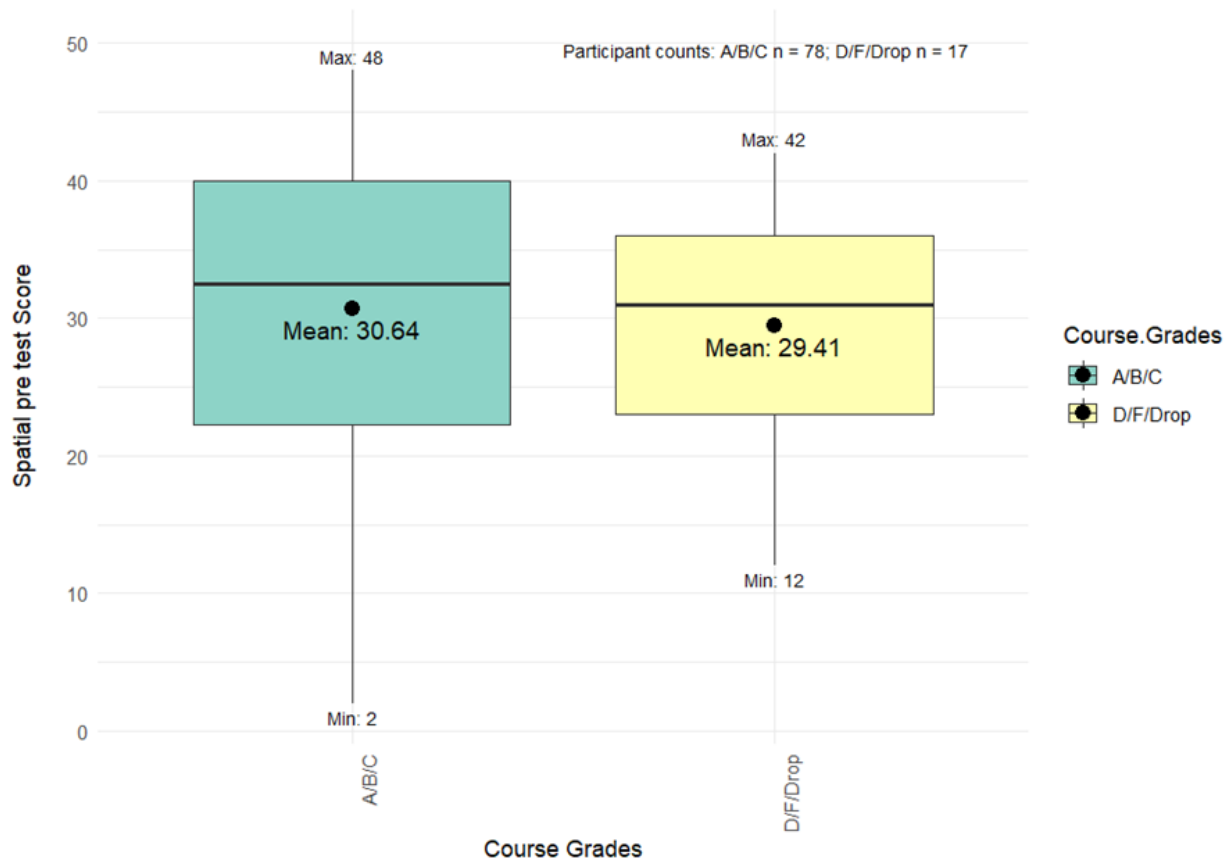


Figure 1: Spatial Pre-Test Score vs Course Grade

Figure 2 shows the box plot of spatial post-test scores of participants of A/B/C group (n = 63) and D/F/Drop group (n = 3). The mean spatial post-test score of A/B/C group is 34.9 and the mean spatial post-test score of the D/F/Drop group is 32.67. The p-value from the Shapiro test is 0.0002444 (< 0.05), indicating the spatial post-test scores are not normally distributed. The p-value obtained from a Mann-Whitney Wilcoxon test is 0.8053 (> 0.05), which implies that there is no significant difference in spatial post-test scores among these two groups. These results suggest that even near the end of the course spatial skills alone did not play a major role in students' successful completion of a Sophomore-level statics course. Other factors may contribute to a student successfully completing the statics course. Alternatively, any number of non-spatial-skill-related factors could have contributed to the students who did not successfully complete the statics course.

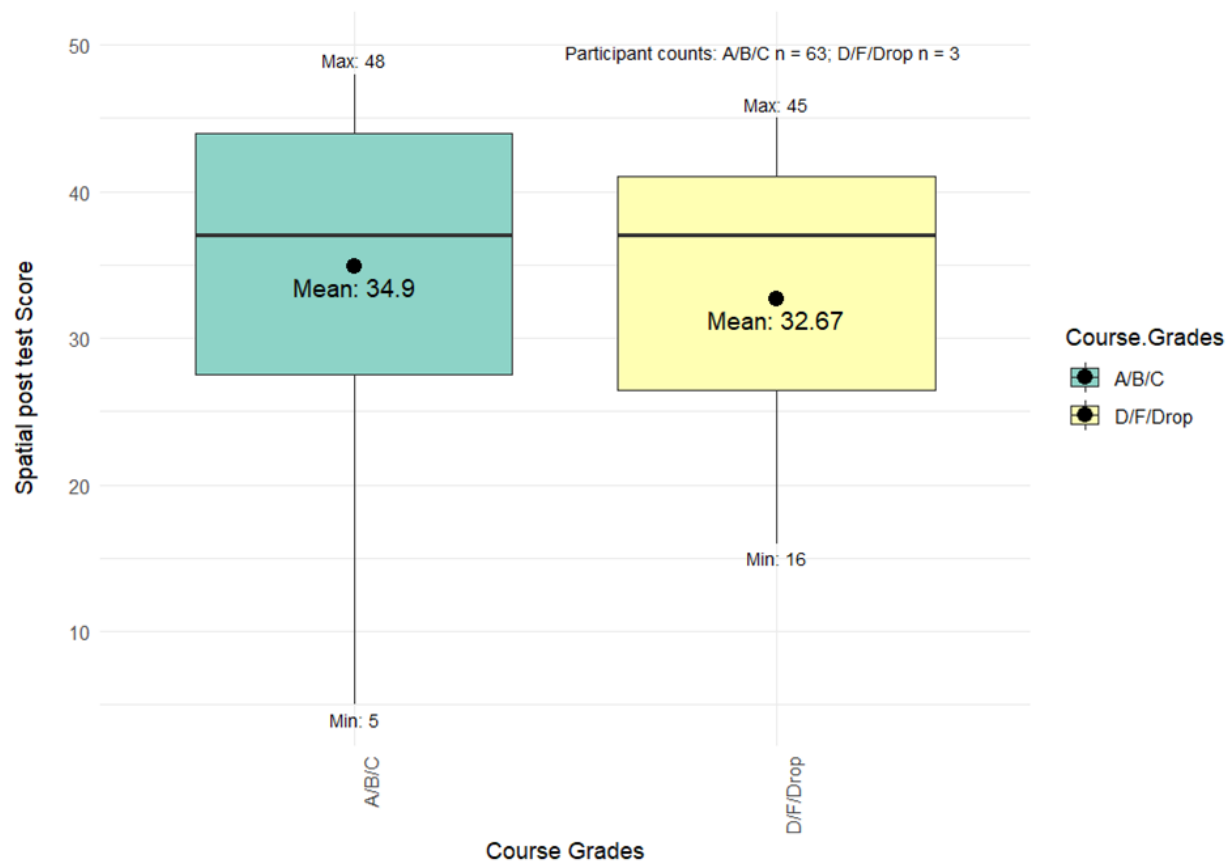


Figure 2: Spatial Post Test Score vs Course Grade

Students' spatial skills are assessed and compared at the beginning and end of the statics course to determine if spatial skills may have been enhanced over the duration of the course. Figure 3 illustrates that the mean score on the spatial pre-test is lower than the mean score on the spatial post-test. The p-value from the Shapiro test is 0.0418, which is less than 0.05, indicating that the data are not normally distributed. A Mann-Whitney test reveals a significant p-value (1.624×10^{-6}), suggesting that the difference of score of these two groups are statistically significant. Therefore, it can be concluded that the statics course contributed to the improvement of spatial skills.

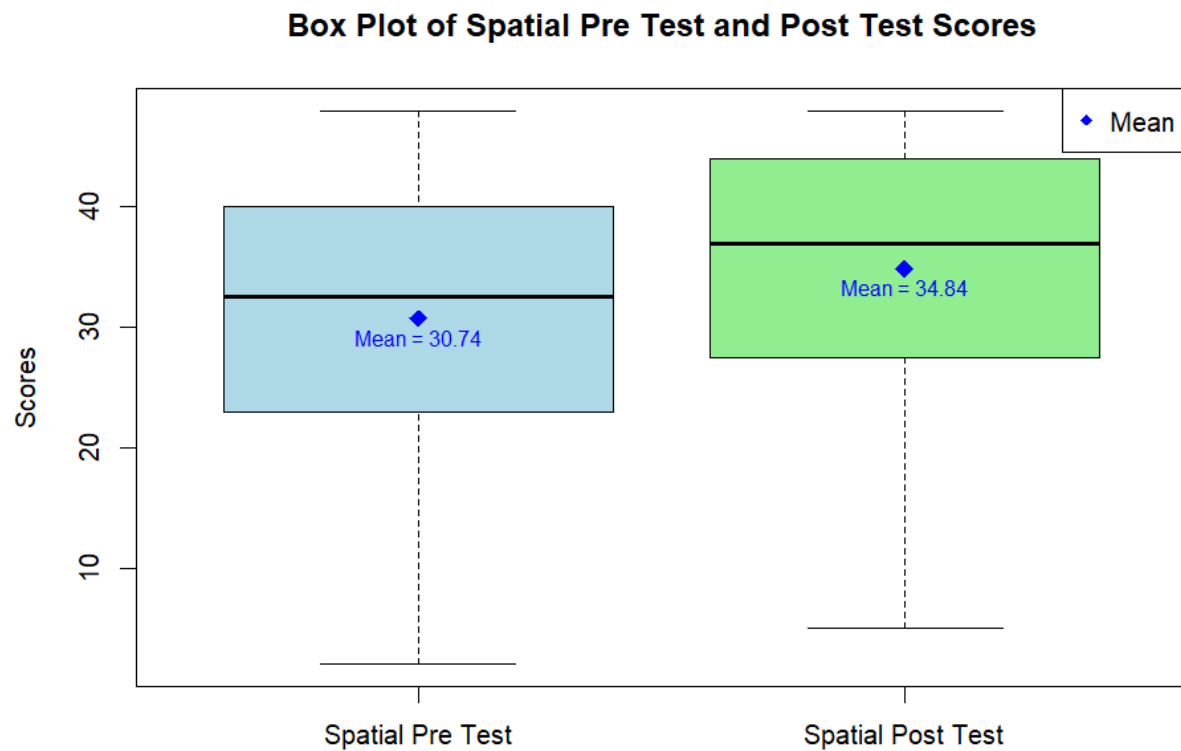


Figure 3: Spatial Pre-Test Score vs Spatial Post-Test Score

Table 1: Spatial Pre-test and Post-Test Score Comparison by Question

Question No.	Mean Spatial Pre-Test Score	Mean Spatial Post-Test Score	p-value (Wilcoxon Test)	Comments
Q1	3.46	3.59	0.02	Significantly different
Q2	3.51	3.53	0.84	Not different
Q3	3.26	3.37	0.37	Not different
Q4	2.69	3.09	0.002	Significantly different
Q5 (changed between pre and post-test)	3.16	2.62	0.007	Not different
Q6	3.01	3.16	0.21	Not different
Q7	2.75	3.15	0.001	Significantly different
Q8	2.65	3.24	0.006	Significantly different
Q9	2.5	2.94	0.01	Significantly different
Q10	1.32	2.07	0.0002	Significantly different
Q11	1.49	2.43	6.662e-05	Significantly different
Q12 (changed between pre and post-test)	0.93	1.66	0.007	Significantly different
Changed Questions (cumulative: Q5 and 12)	4.09	4.28	0.5493	Not different
Unchanged Questions (cumulative: Q1-4, Q6-11)	27.57	30.56	0.0001939	Significantly different

The equivalence of the spatial test question is evaluated by comparing pre and post-test scores of each question. Table 1 shows each question score comparison of spatial pre-test and post-test. Mann Whitney Wilcoxon test is used to compare scores of pre and post-test question scores, as they are not normally distributed. Question 5 and 12 of the post-test are new questions that were not on the pre-test. Question 5's score increased while Question 12's score decreased. For old

questions, question 1, 4, 7, 8, 9, 10 and 11 scores increased while question 2, 3, and 6 scores remain the same both in pre-test and post-test. So, it can be said that familiarity with questions doesn't affect test scores.

Math skills were compared between groups A/B/C and D/F/Drop to determine whether they influenced students' performance in the statistics course. Figure 4 presents a box plot of the math pre-test scores for both groups. Interestingly, the plot shows that the mean pre-test score for group A/B/C is lower than that of group D/F/Drop. The pre-test math data do not follow a normal distribution, as the p-value from the Shapiro-Wilk test is 0.002133 (> 0.05). The p-value from the Mann-Whitney Wilcoxon test is 0.4609, indicating there was no significant difference in trigonometry-based math skills between the two groups at the start of the course.

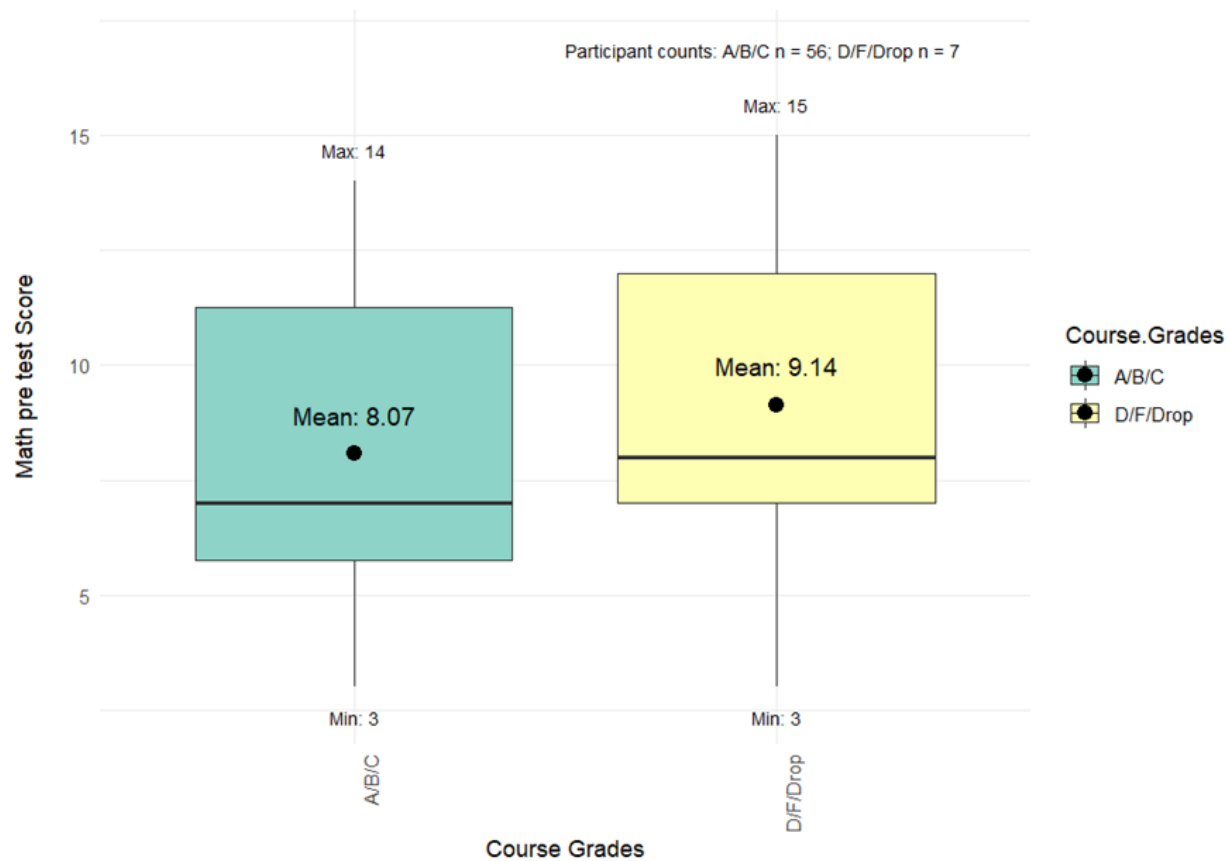


Figure 4: Math Pre-Test Score vs Course Grade

Figure 5 shows the math post-test scores categorized by course outcome grade groups. The mean post-test score for group D/F/Drop is again higher than that of group A/B/C. The p-value from the Shapiro-Wilk test is 0.04726, indicating that the math post-test scores are not normally distributed. A Mann-Whitney Wilcoxon test revealed a non-significant p-value of 0.092 ($p > .05$), suggesting no significant difference of math post-test score between two groups. The results of the pre- and post-math tests would seem to indicate that trigonometry ability does not significantly contribute to course outcome in the statics course.

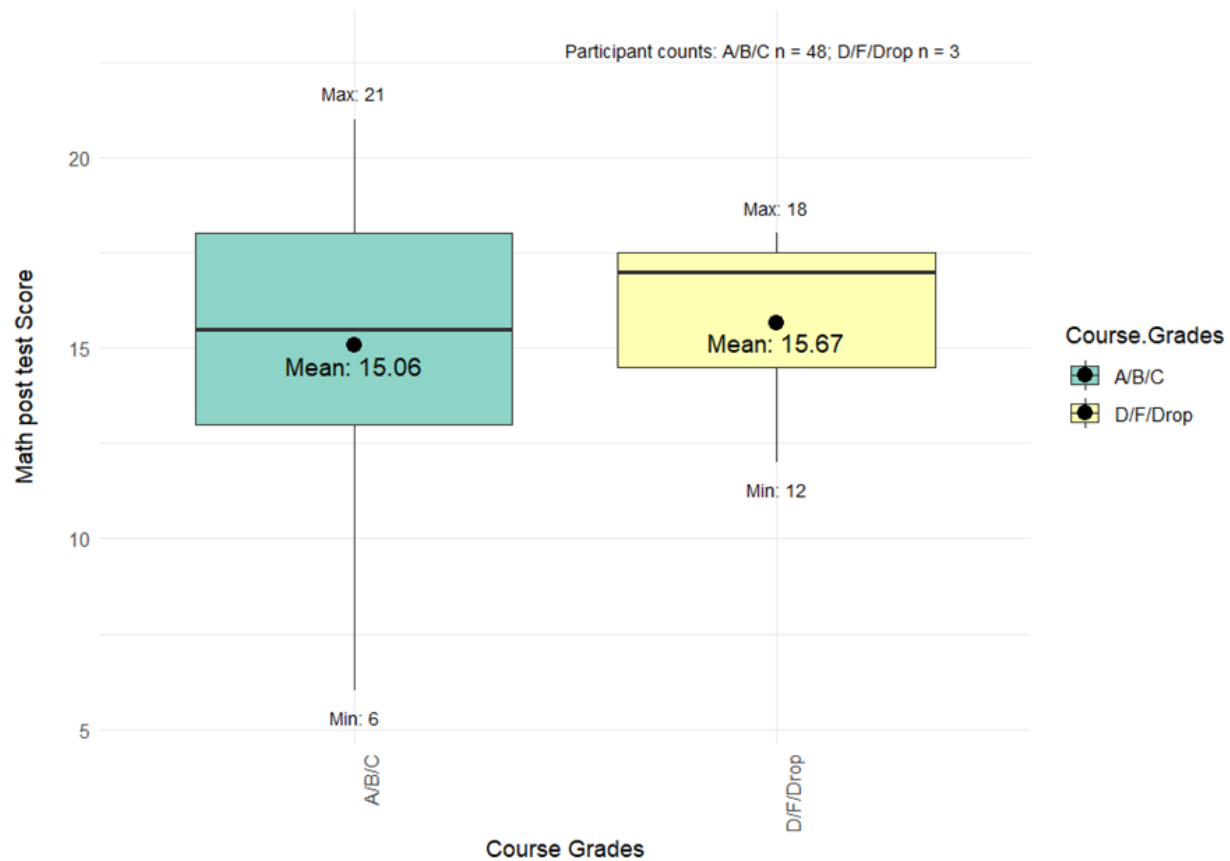


Figure 5: Math Post-Test Score vs Course Grade

Participants' math skills are also considered by participants' math section score from the ACT/SAT test.

Participants' math section score from ACT and SAT tests are also compared between the A/B/C group and the D/F/Drop group. Figure 6 shows that the mean math section score of group A/B/C is higher than group D/F/Drop. A Shapiro test resulted in a p-value of 0.2247 (> 0.05), indicating that that ACT Math score is normally distributed. An unpaired t-test revealed a p-value of 0.1659 (> 0.05), meaning that the difference of ACT Math score of group A/B/C and D/F/Drop is not statistically significant.

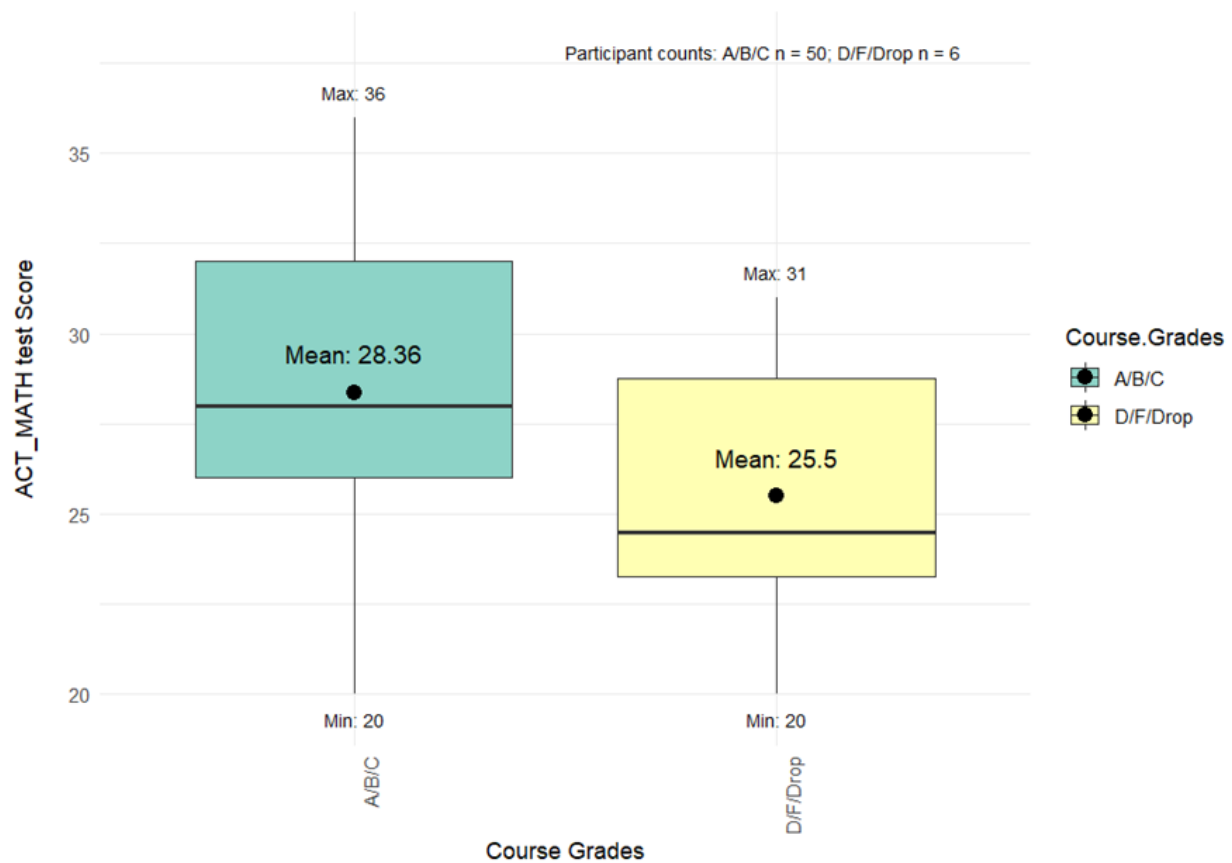


Figure 6: ACT Math Test Score vs Course Grade

Figure 7 shows the SAT Math section score by course grade. The mean SAT Math score of group A/B/C is less than D/F/Drop group. The p-value obtained from the Shapiro test is 0.141 (>0.05), showing that the SAT Math test score data is normally distributed. The p-value obtained from an unpaired t-test is 0.9345 (>0.05), indicating that the SAT math score of these two groups are not significantly different. The analysis of both ACT and SAT math scores by course grade outcome group shows that ACT/SAT math test score is not an indicator of the performance of a student in their statics course.

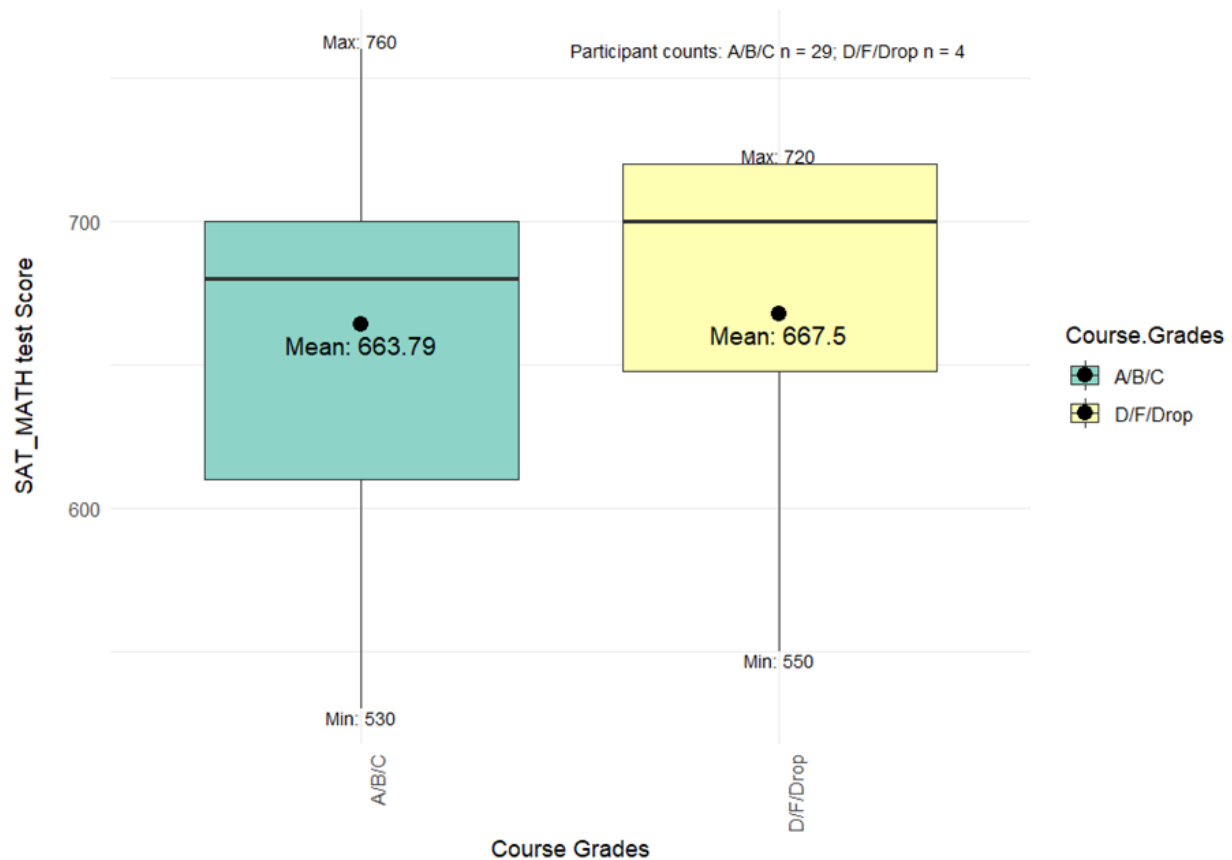


Figure 7: SAT Math Test Score vs Course Grade

A correlation test was conducted to examine the relationship between spatial skills and math skills. Figures 8, 9, and 10, 11 show scatter plots comparing math skills with spatial skills. Figures 7 and 8 indicate a general increase in spatial test scores as math test scores increase. The Pearson correlation coefficient for the math pre-test and spatial pre-test scores is $r = 0.3077$, while the coefficient between the math post-test and spatial post-test scores is $r = 0.4481$.

The math scores from participants' ACT and SAT exams were compared to the spatial exam pre-test to further investigate the relationship between spatial skills and math skills. Figures 10 and 11 illustrate the scatter plots of ACT and SAT math scores against spatial pre-test scores, accordingly. Both show an increasing trend from left to right. The Pearson correlation coefficient for the ACT math score and spatial pre-test score is $r = 0.3154$, while the correlation coefficient between the SAT math score and spatial pre-test score is $r = 0.2055$.

In all four comparisons, the Pearson correlation coefficients are below $r < 0.5$, indicating that spatial skills and math skills have only a moderate correlation, suggesting that math skills are not a strong predictor of spatial skills.

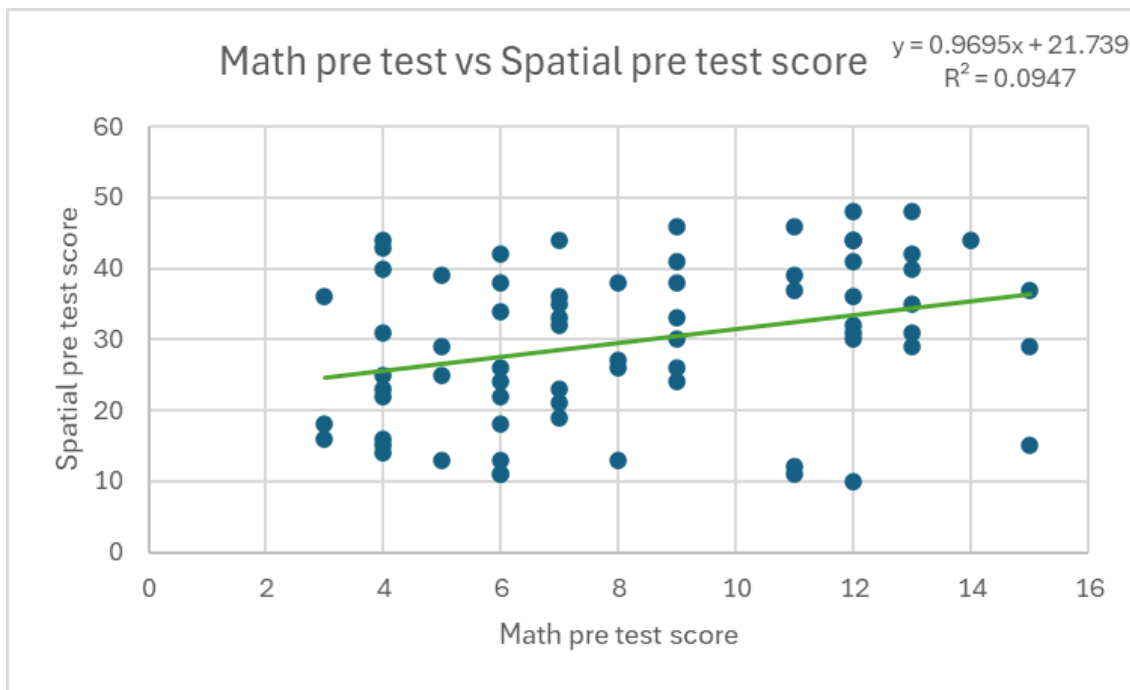


Figure 8: Spatial Pre Test Score vs Math Pre Test Score

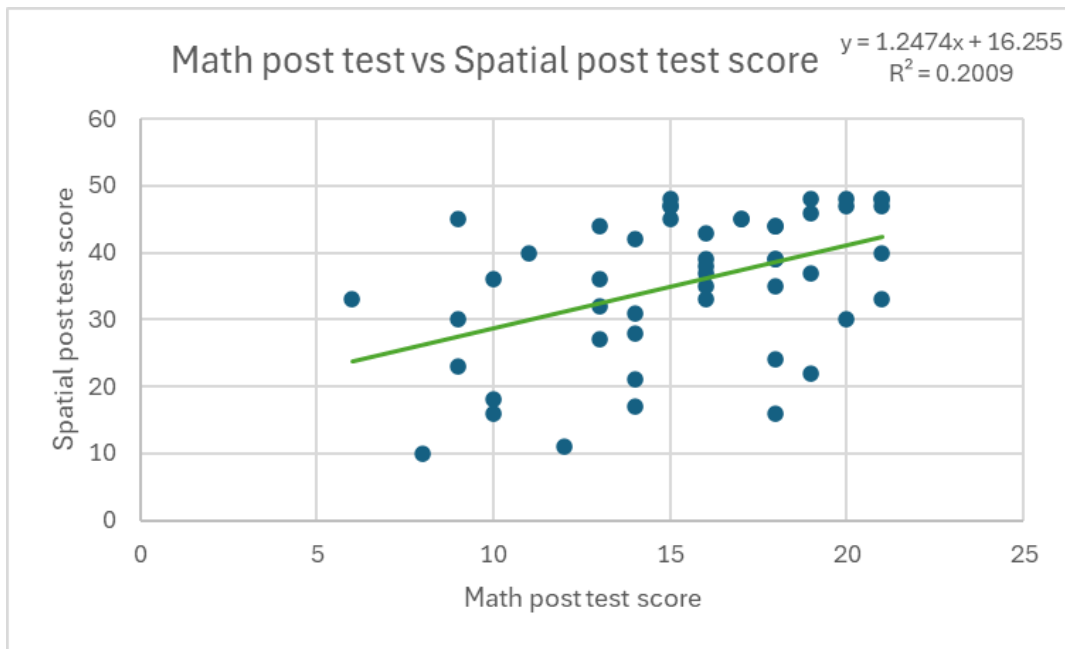


Figure 9: Spatial Post Test Score vs Math Post Test Score

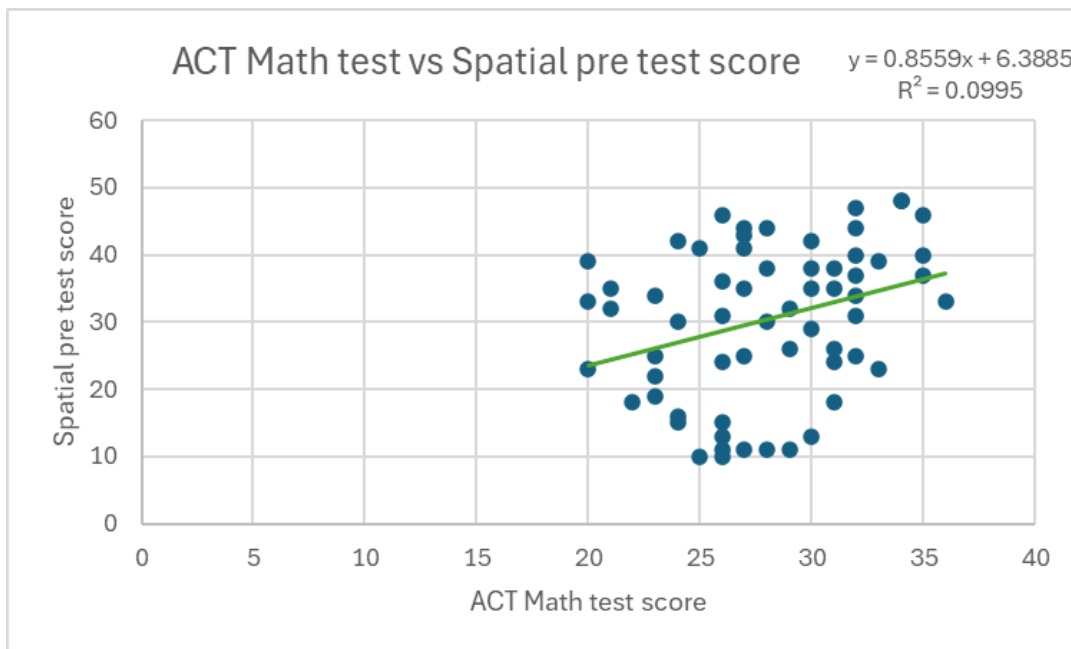


Figure 10: Spatial Pre Test Score vs ACT Math Test Score

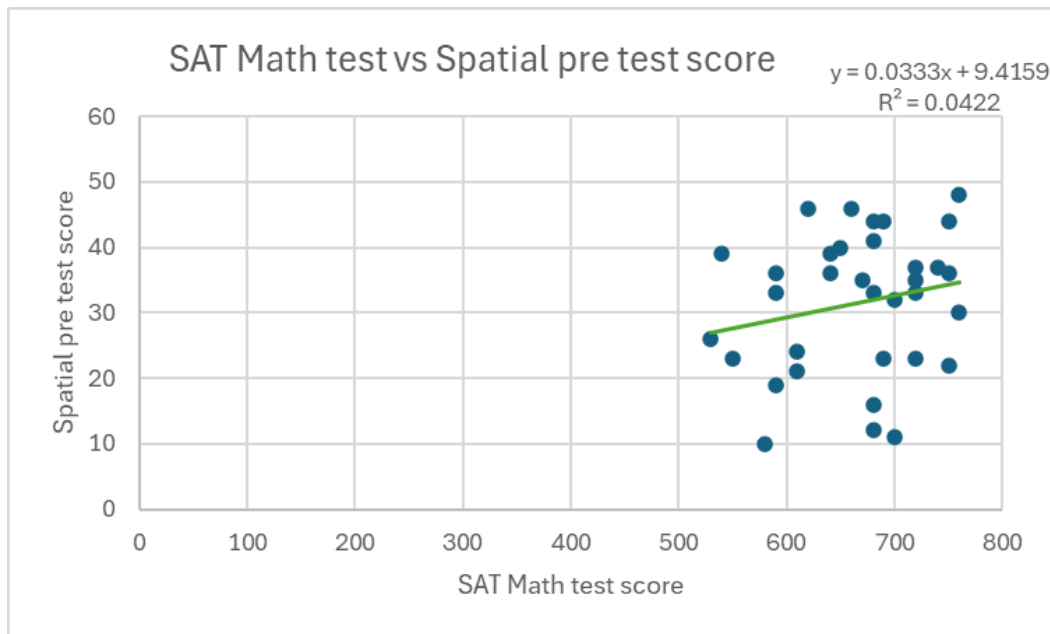


Figure 11: Spatial Pre Test Score vs SAT Math Test Score

The effect of ACT English, ACT Reading, ACT Science Reasoning, and SAT Reading/Writing scores on statics course grades are also analyzed between the A/B/C and D/F/Drop groups. The mean ACT English and ACT Science reasoning scores of the A/B/C group are higher than the scores of the D/F/Drop group, though these results were not significant. Interestingly, the mean ACT Reading and SAT Reading/Writing scores of the A/B/C group are lower than the D/F/Drop group, though this effect again was not significant.

The Pearson correlation coefficient of Spatial pre-test and ACT English is 0.11, spatial pre-test and SAT Reading/Writing is 0.18, which shows a weak correlation between Spatial skill and English writing skill.

Math test scores are also compared with ACT/SAT math scores. Figure 12 and 13 compares math test score with ACT math score. Figure 14 and 15 compares math test score with SAT math score. Table 2 shows the Pearson correlation coefficient of math test score and ACT/SAT math score. The correlation coefficient of math pre test score and ACT Math Score is $0.399 < 0.05$ which indicate a moderate correlation. However other math test scores are strongly correlated with ACT/SAT math score, with correlation coefficient greater than 0.05, which means that those students who did well at ACT/SAT math did well at math test

Table 2: Comparison of Math Test Score vs ACT/SAT Math Score

Figure no	Comparison		Correlation Coefficient
Figure 12	Math Pretest Score	ACT Math Score	0.399
Figure 13	Math Posttest Score	ACT Math Score	0.56
Figure 14	Math Pretest Score	SAT Math Score	0.584
Figure 15	Math Posttest Score	SAT Math Score	0.684

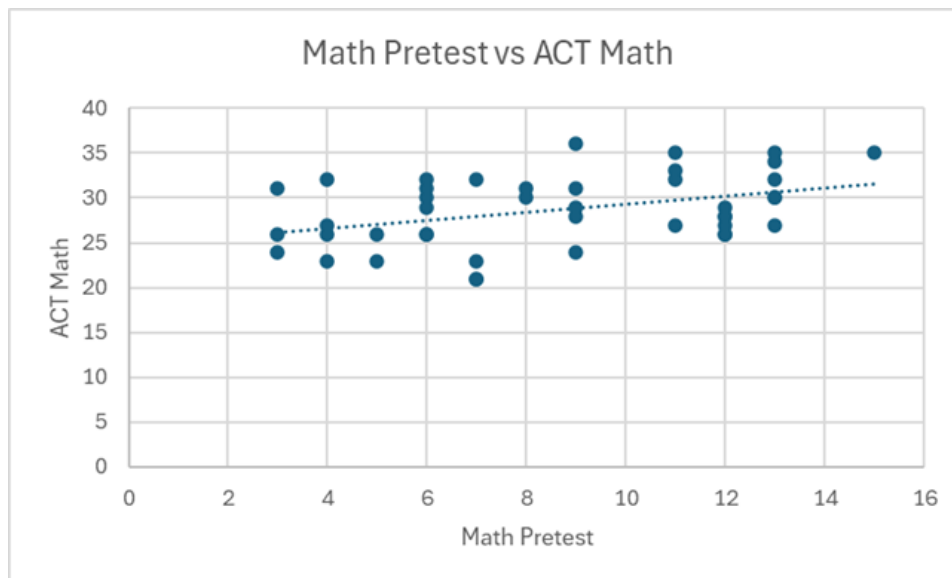


Figure 12: Math Pre Test Score vs ACT Math Test Score

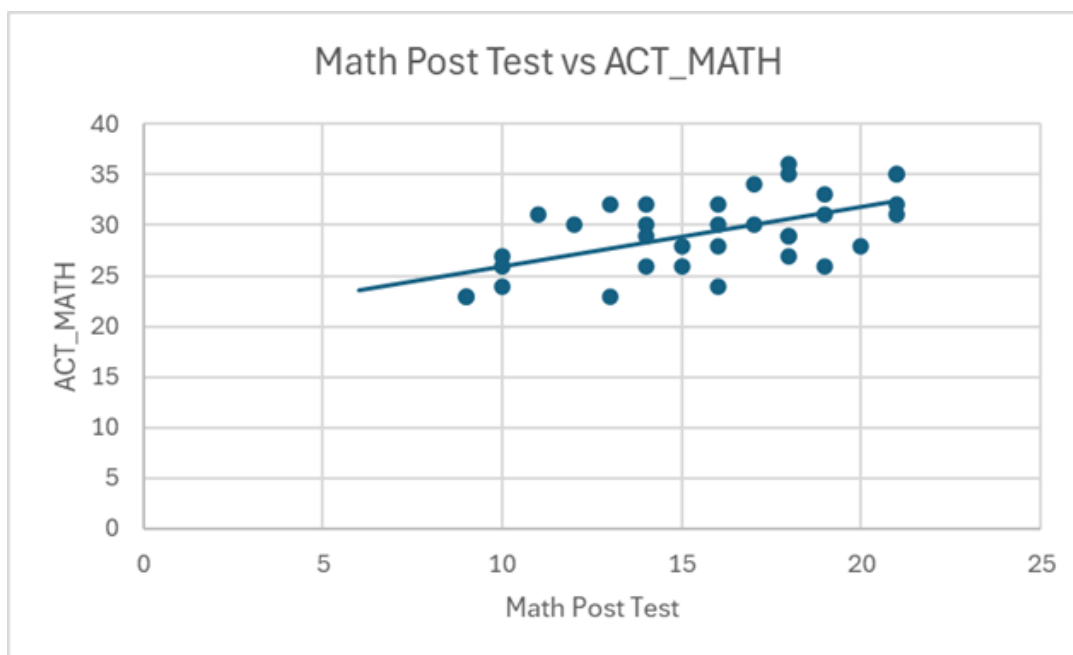


Figure 13: Math Post Test Score vs ACT Math Test Score

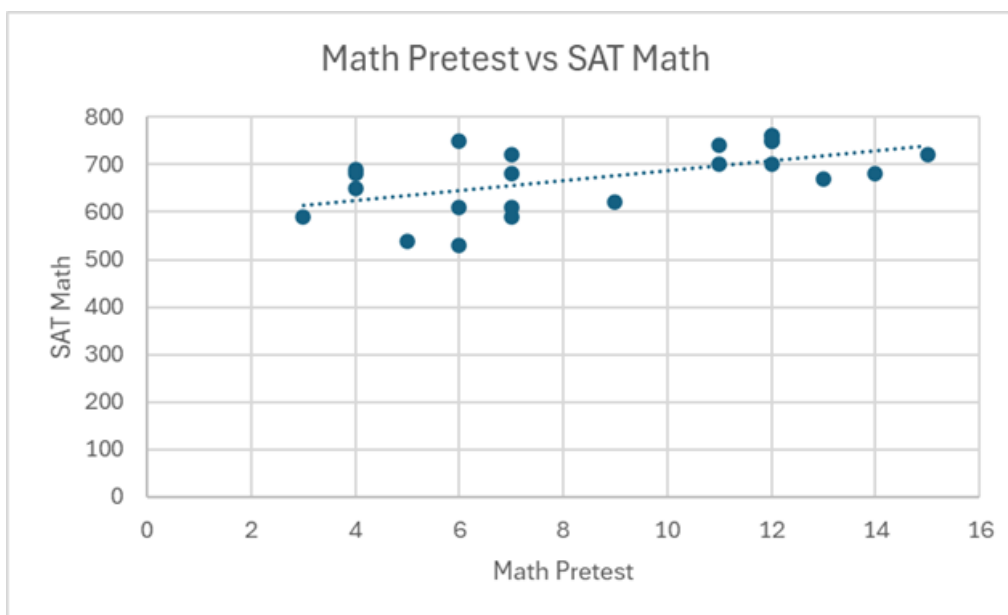


Figure 14: Math Pre Test Score vs SAT Math Test Score

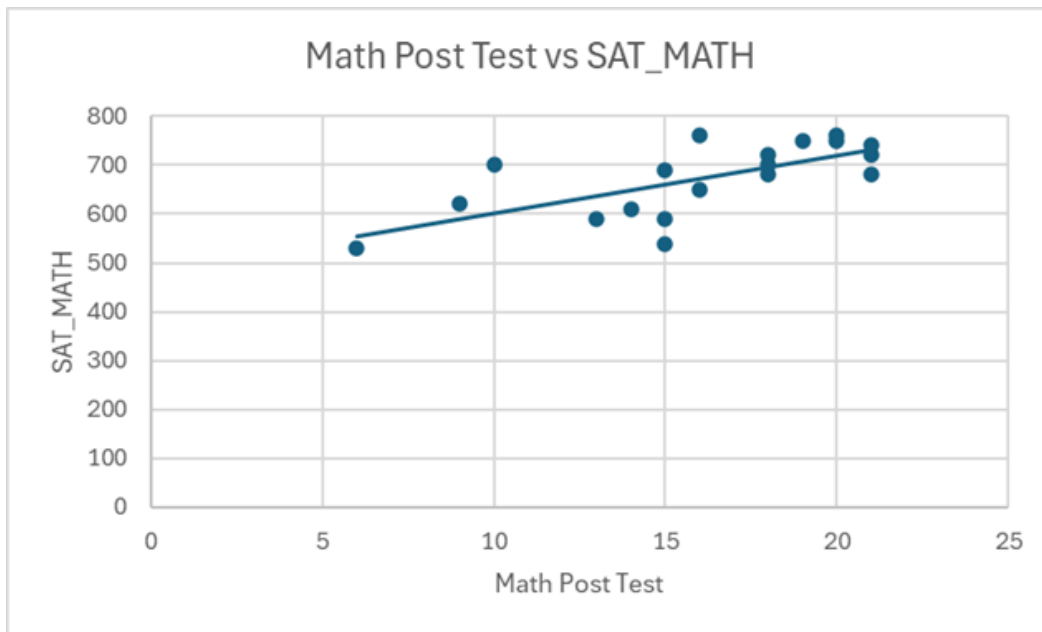


Figure 15: Math Post Test Score vs SAT Math Test Score

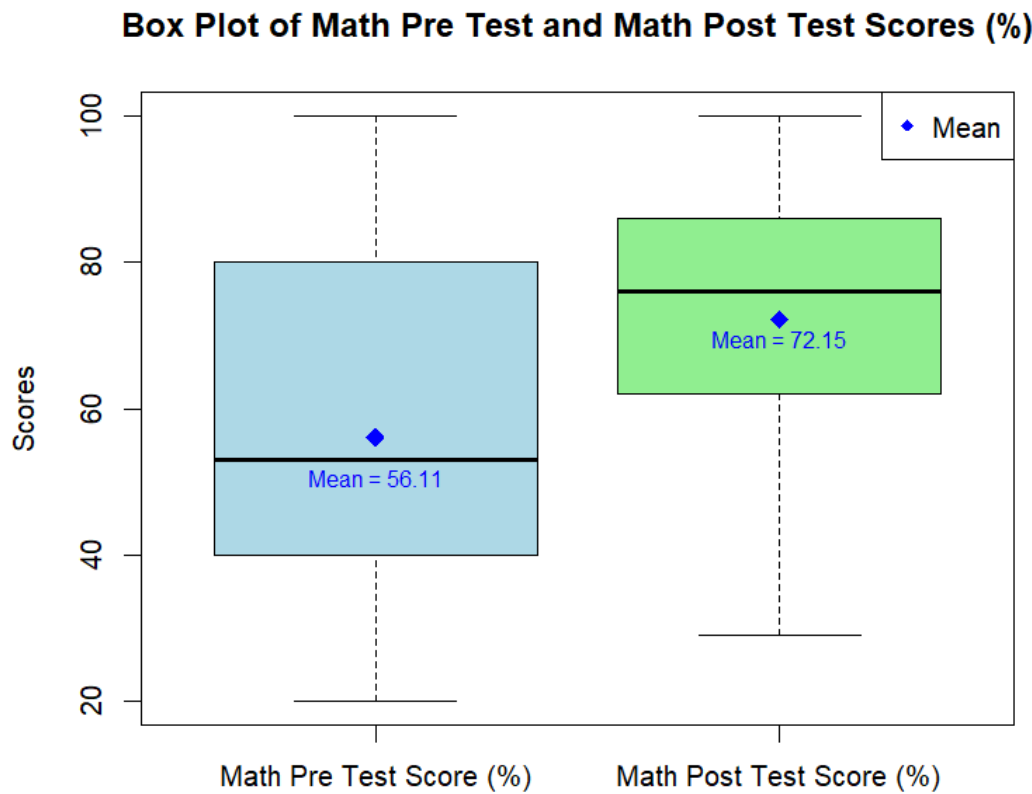


Figure 16: Math Pre-Test vs. Post-Test Score

The figure 16 shows the comparison of math test scores at the beginning and at the end of the course. The p value is 1.907e-06 from Mann Whitney Wilcoxon test, which means that the math post test score is significantly higher than math pre test score.

Other factors that could be related to spatial skills are also analyzed. Spatial skills as an effect of different gender identities or familiarity with previous CAD courses are investigated. Figures 17 and 18 show the comparison of Spatial skills of different gender identities. The number of participants of the gender category prefer not to say is 1, which is very low and were omitted from analysis. A Mann-Whitney Wilcoxon test run from the spatial pre-test data yielded a significant p-value of 0.02856, while the same test with the spatial post-test data resulted in $p = 0.00787$. In both cases, the p-values were less than 0.05, indicating that the spatial skills of males in this test group are significantly higher than females.

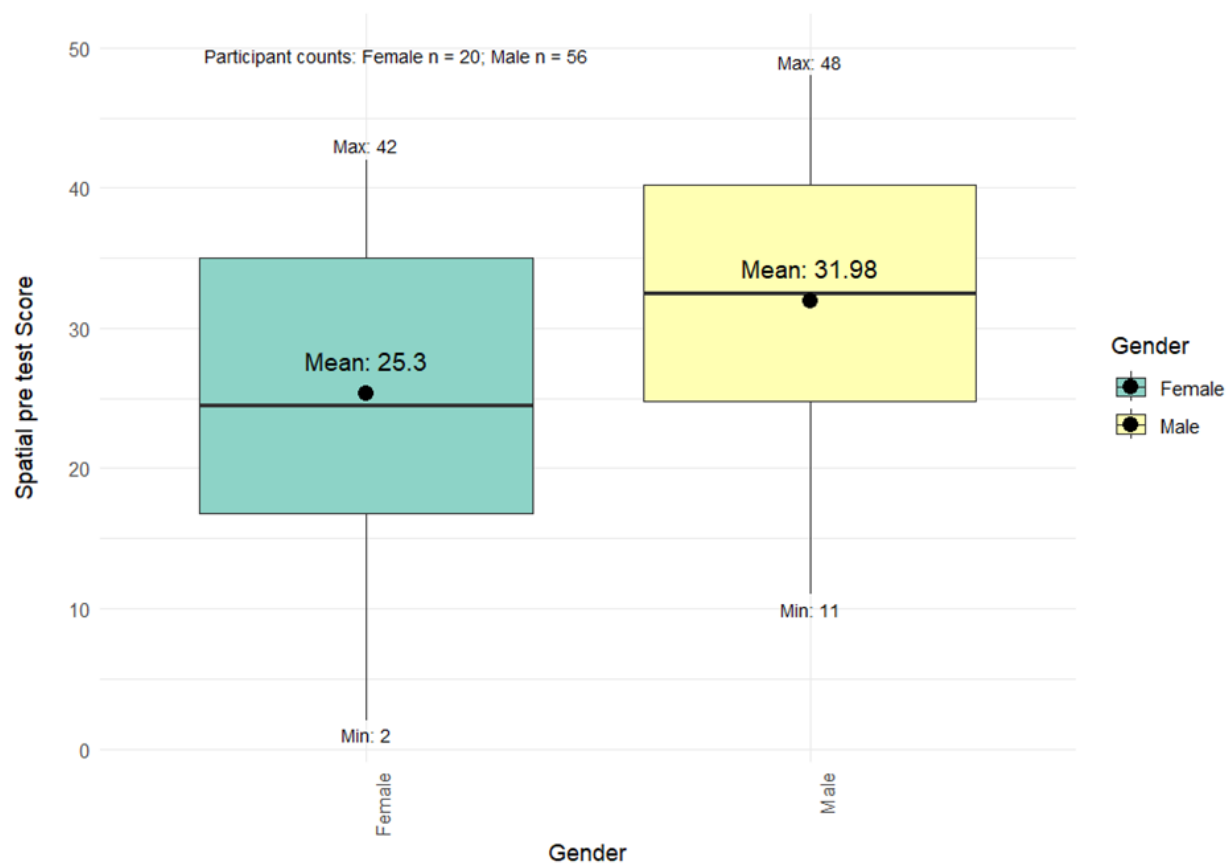


Figure 17: Spatial Pre-Test Score vs Gender

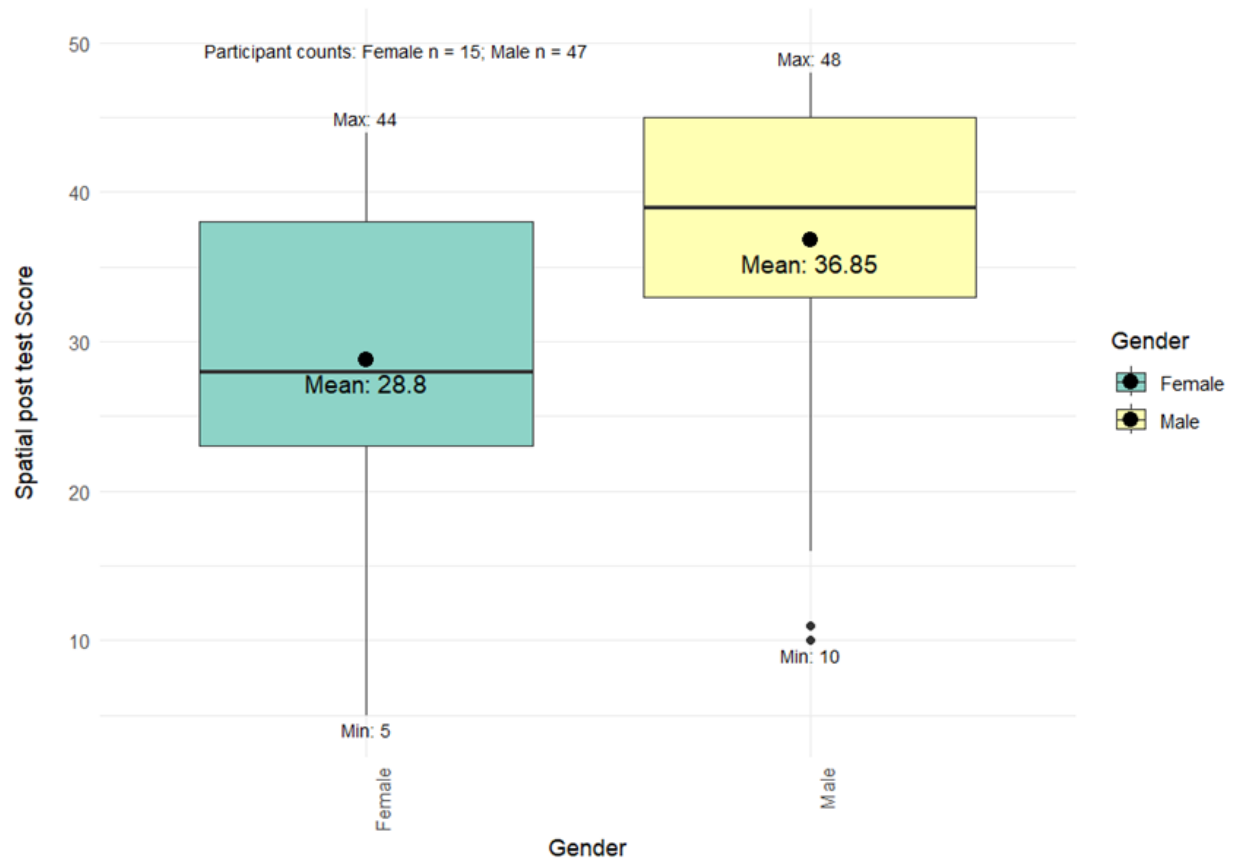


Figure 18: Spatial Post-Test Score vs Gender

Spatial skills are evaluated based on participants' familiarity with CAD or drafting course. Figure 19 and 20 show the spatial test scores of the group of participants i) who have never taken a CAD/Drafting course, ii) who have taken a CAD/Drafting course before entering the college and iii) who have taken or are taking a CAD/Drafting course while in college. Both figures show that students who participated in CAD courses before entering college have better spatial skills than those who either never took a CAD course or those students who took their first CAD course while in college. The p -value obtained from the Kruskal-Wallis test is 0.044 for spatial pre-test and 0.016 for the spatial post-test. In both cases, the p -value is less than 0.05 indicating there is a significant difference of spatial skill among these three groups. A Dunn test, used to determine which groups are different, shows that the p -value of comparing the group 'No' and 'before entering the college' is 0.03 (< 0.05) for the spatial pre-test and 0.04 (< 0.05) for the post-test. Thus, the spatial skill abilities from both the pre- and post-tests between groups i) students who had never taken a CAD/Drafting course were significantly different from group ii) students who had taken CAD/Drafting prior to college. These results suggest that familiarity with CAD courses prior to entering college has a greater influence in improving spatial skills than for those who take a CAD course later in life.

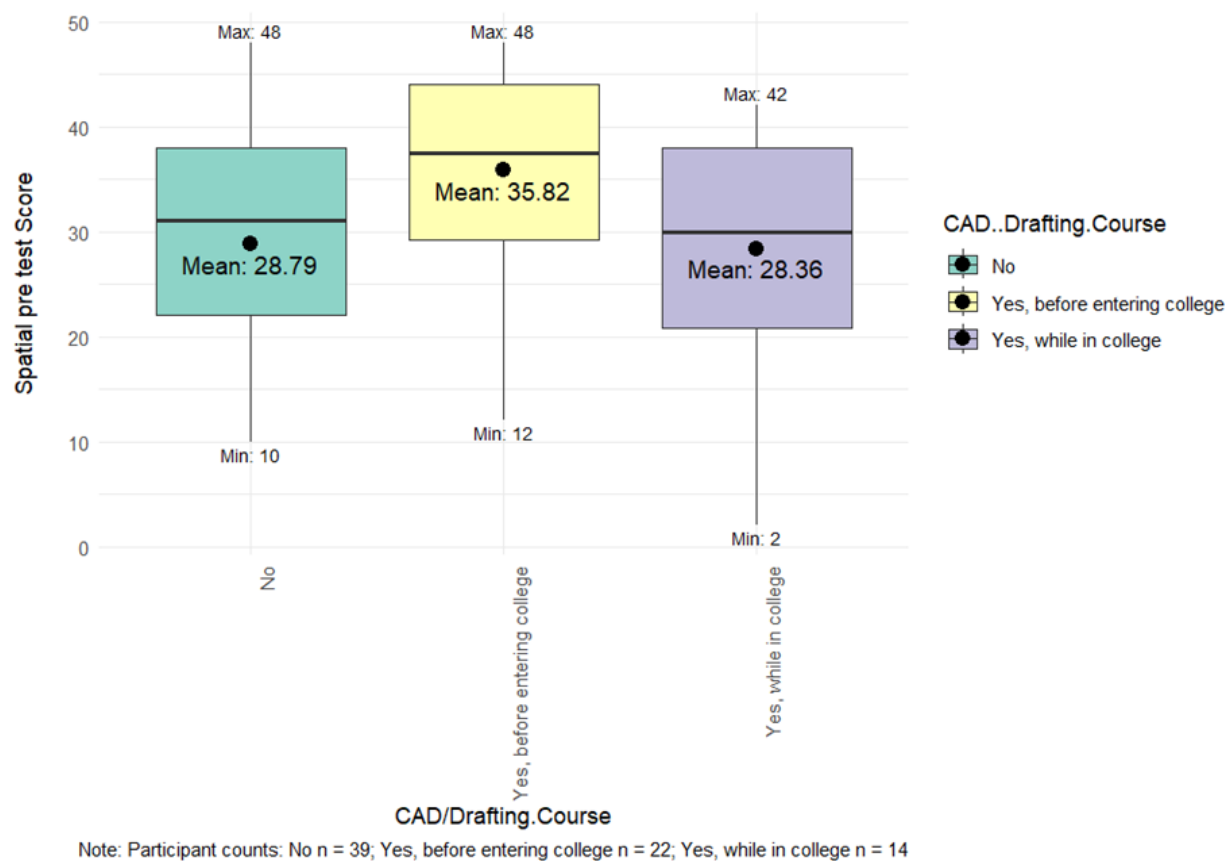


Figure 19: Spatial Pre-Test Score vs CAD/Drafting Course

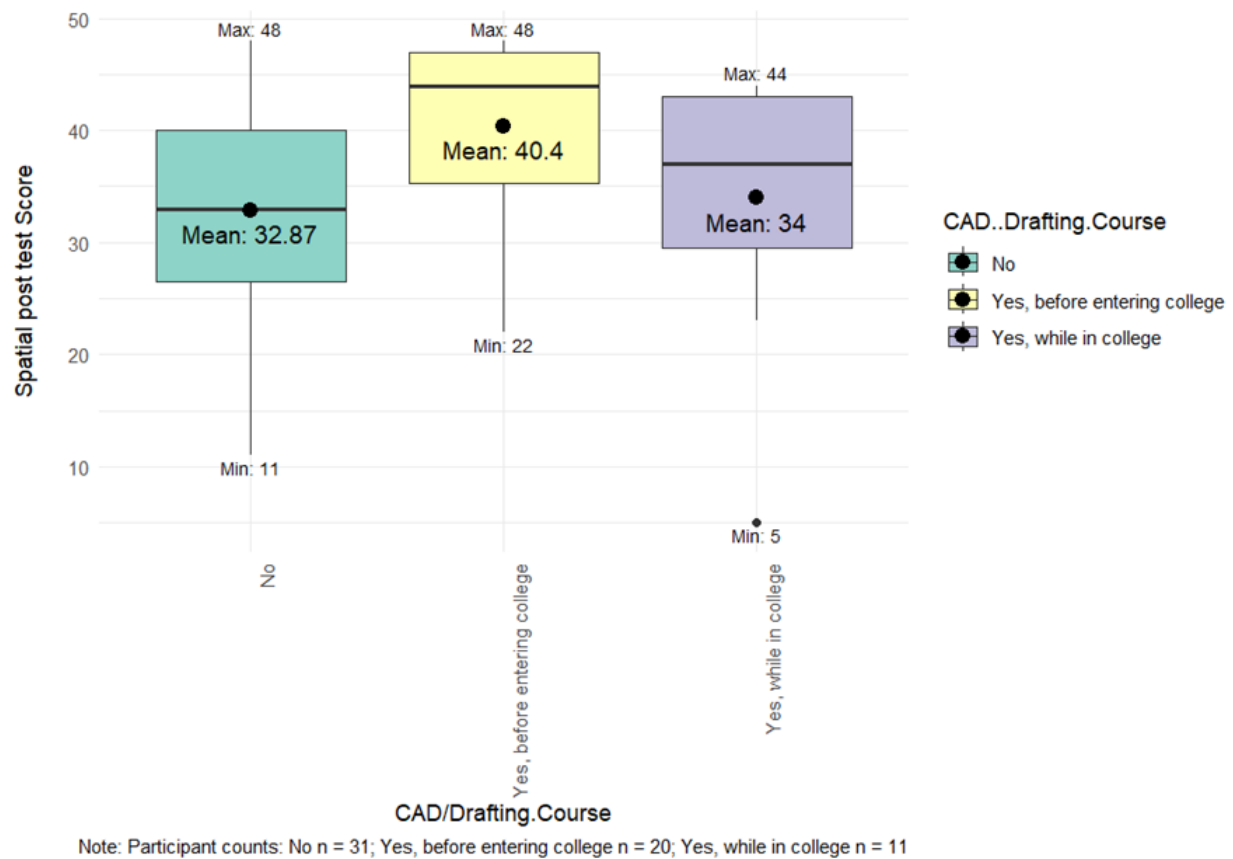


Figure 20: Spatial Post-Test Score vs CAD/Drafting Course

The research sought to determine if the higher spatial skill scores observed in male participants (Figures 17 and 18) were influenced by a greater number of males taking CAD/Drafting courses. To isolate this factor, the study compared the spatial pre-test of male and female participants who had and *had not* taken such courses before entering college. Because there was no significant difference seen between the spatial skills of students who had never taken a CAD course and students who had first taken a CAD course in college these two groups were merged into a “Did not take CAD before college” group.

Comparison of Spatial Pre Test Scores by Group

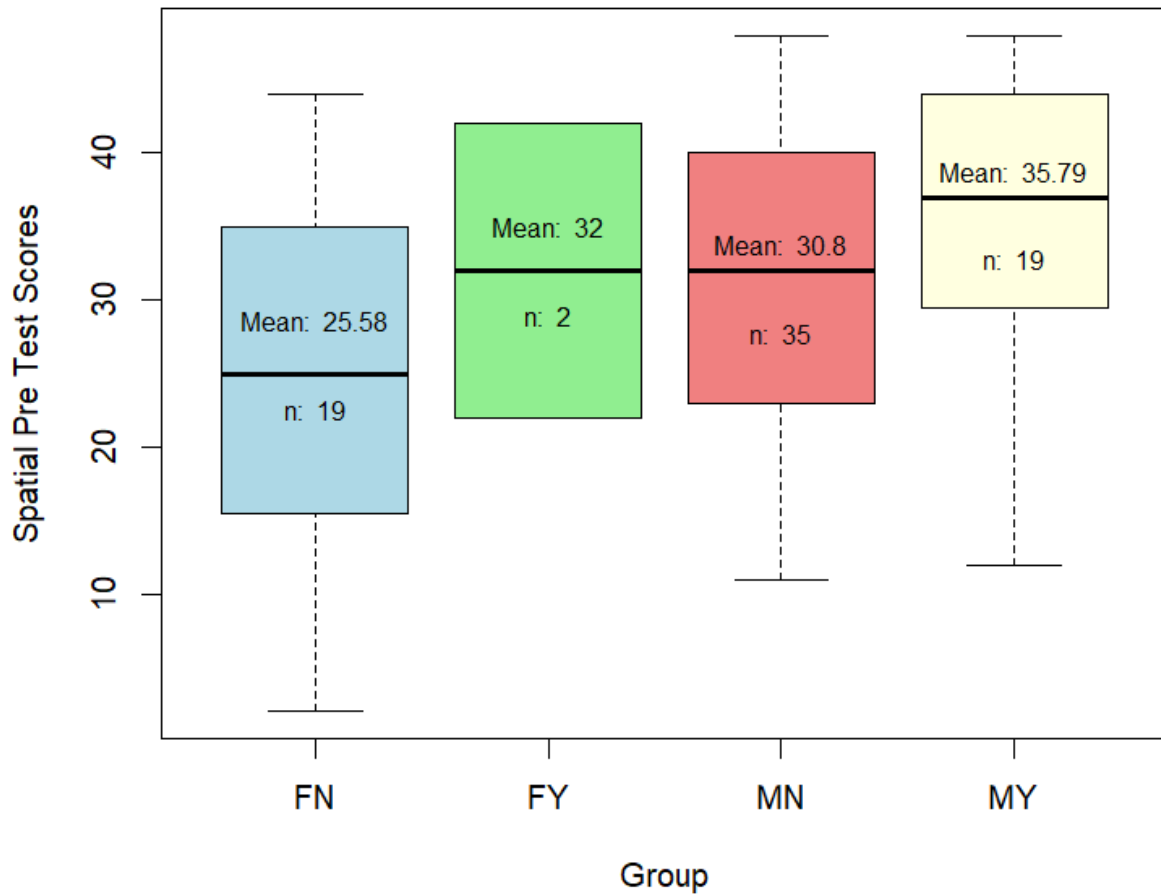


Figure 21: Spatial Pre-Test Score vs CAD Experience and Gender

Group Details	
FN	Female students who either have never taken a CAD/drafting course or who have taken a CAD/drafting course for the first time in college.
FY	Female students who have taken a CAD/drafting course before entering college
MN	Male students who either have never taken a CAD/drafting course or who have taken a CAD/drafting course for the first time in college
MY	Male students who have taken a CAD/drafting course before entering college
n	Number of participants

The FY group is excluded from the analysis as the number of participants in the FY group is 2. The p-value from the Kruskal-Wallis test is $0.0266 < 0.05$, which means that there are significant differences among these three groups, FN, MN, and MY.

The Dunn test comparing FN and MN resulted in a p-value of 0.1982, indicating that gender does not play a significant role in the spatial skill abilities of those students who did not take a CAD/Drafting course before college.

The p-value from the Dunn test comparing FN and MY is 0.01, indicating there are significant differences between the spatial pre-test scores of the FN and MY groups. The spatial pretest score of females who didn't take CAD/Drafting courses before entering college is significantly lower than males who took CAD/Drafting courses before entering college. This effect is likely due to the increased ability of students who took a CAD/Drafting courses before entering college (shown in Figure 18), and not due to a gender effect, although additional testing, with larger sample sizes for FY group, is needed.

A Mann-Whitney Wilcoxon test is used to compare the pre-test spatial skill scores between FY and MY groups. Due to the low sample size of FY ($n = 2$), the *approximate* p-value is 0.5892. Because the sample size is so small no conclusions can be drawn from the data, however the existing data for spatial skills of female students who took a CAD course before college appears to be within range of the spatial skill of male students who took a CAD course before college. Thus, there may be no gender difference among students who took a CAD course before entering college. More data is required to draw firm conclusions.

Participants' spatial skills were also evaluated based on ethnicity, current engineering major, high school graduation class size, final math course taken in high school, and whether or not the participant had ever taken an art course, shop class, or industrial tech class to find whether there is any effect of these factors on spatial skills. No significant differences were found among means of spatial skill test scores among these various groups based on these variable factors.

Discussion

The findings from this study contribute significantly to our understanding of the interplay between spatial skills, mathematics skills, and academic performance in engineering education. Contrary to initial hypotheses, spatial skills did not emerge as a significant predictor of success in a sophomore-level engineering statics course. Both spatial pre-test and post-test scores were similar for students who passed (grades A, B, or C) and for those who did not complete the course (grades D, F, or dropped), suggesting that spatial skills alone may not substantially influence students' ability to succeed in this particular academic context. These findings contradict the findings of Parkinson and Cutts (2020), who showed that students enrolled in an introductory computer course, who also underwent voluntary spatial skill training, performed better in the introductory computer class than students who did not participate in the spatial skills training. They concluded that spatial skills training resulted in increased performance in computer programming; however, it is also possible that ambitious students who were already going to excel at computer programming chose to pursue additional spatial skills training. Thus, the findings of the Parkinson and Cutts study may be misinterpreted. It is possible that spatial skills training acted as motivation to do well in introductory computing courses.

Interestingly, despite the lack of correlation with course grades, a notable improvement in both spatial skills and math skills was observed from pre-tests to post-tests. This suggests that the course effectively fosters spatial reasoning abilities, geometry, and trigonometry skills among students. The instructional methods employed in the statics course likely provided opportunities for students to engage in spatial visualization tasks, thereby enhancing their capabilities in this area. Similarly, statics students will utilize geometry and trigonometry repeatedly throughout the course, offering many opportunities to practice these skills. However, the disconnect between improved spatial skills and actual course performance, as well as a disconnect between math skills and course performance, indicate that other factors may be at play, such as students' intrinsic motivation, prior knowledge, study habits, or external pressures.

The analysis also revealed gender differences in spatial skills, with male students outperforming female students in both pre- and post-tests. This finding undermines the findings from the literature by Charlesworth *et al.*, 2005, who didn't find any gender difference in learning outcomes of spatial skills using multimedia software and workbook modules. They ran the experiment on a non-engineering major while our participants were exclusively students majoring in engineering, this could be a reason for the discrepancy in results. This finding prompts discussions about how educational practices may inadvertently reinforce these gaps. These gender differences were not seen, however, when factoring in early spatial learning. There was no difference in spatial skills between female and male students who had not taken a CAD/Drafting course before college and also found no difference in spatial skills between female and male students who had taken a CAD/Drafting course before college. These results are suspect, however, due to the extremely low sample size of female students who take a CAD/Drafting course before college. This again underscores the need for targeted interventions that specifically address the development of spatial skills in female students, potentially through tailored teaching strategies or mentorship programs that foster confidence and competence in spatial reasoning.

Furthermore, the correlation between familiarity with CAD courses taken prior to college and

higher spatial skills suggests that early exposure to spatially oriented learning experiences has a lasting impact on students' spatial abilities. Šafhalter (2020) discovered that integrating spatial modeling using SketchUp in early technology education greatly improves children's spatial visualization skills. This reinforces the argument for integrating spatial skills training into earlier educational curricula, allowing students to build a foundation that supports their success in engineering programs. Programs that provide hands-on experiences in drafting or design could serve as effective vehicles for enhancing spatial skills and fostering greater engagement in STEM fields. This study demonstrated the incredible need for early spatial skills learning and the need for more diversity among early learners.

This study did not find any effect of math skills on students' course grades and did not find any correlation between math skills and spatial skills. These findings contradict the findings of Hawes *et al.*, 2022, whose research found a relation between spatial skills and mathematics skills. They found that spatial skill training improves spatial thinking and improving spatial skill improves mathematics understanding, although they were unable to explain the mechanism of this skill transfer. Similarly, Atit *et al.*, 2020 also found a link between spatial skills and student's motivation in mathematics. Their findings could be due to the participant's age in their study. Atit *et al.*'s study included 7th-grade students, aged ~12 years old, with diverse interests in their future careers. Some of these students would grow to pursue stem futures such as engineering, biology, chemistry, physics etc, and would presumably have an interest in both math and spatial skills activities; however, some of the students in Atit *et al.*'s study would be disinterested in math a spatial skills activities and presumably would pursue non-stem futures. The more diverse population, with a wider set of interests, could have led to a stronger correlation between math skills and spatial reasoning skills. The correlation between spatial reasoning skills and math skills in the present study could likely have been stronger had the present study included a more diverse population that included non-stem majors.

Conclusion and Future Research

In conclusion, this research illuminates the complex factors that influence student success in engineering courses, particularly in the realm of spatial and mathematical skills. While spatial skills are crucial and can be developed through structured coursework, they do not serve as definitive predictors of academic performance in a sophomore-level statics course. Other factors—such as prior coursework or motivational variables—may play more significant roles in shaping students' outcomes.

The significant improvement in spatial skills following the course emphasizes the potential of well-designed educational interventions to enhance these competencies, thereby preparing students for the demands of engineering professions. However, the findings also highlight the necessity for a more nuanced understanding of how various factors contribute to academic success, particularly in light of gender disparities and the importance of prior experiences with spatial tasks.

Future research should continue to explore the role of these dynamics with larger and more diverse populations. To improve the robustness of the test participants could be motivated with incentives such as payment or class credit.

References

1. Alvarez-Vargas, D., Abad, C., & Pruden, S. M. (2020). Spatial anxiety mediates the sex difference in adult mental rotation test performance. *Cognitive Research: Principles and Implications*, 5(1). <https://doi.org/10.1186/s41235-020-00231-8>
2. Azzam, I., Breidi, F., Aqlan, F., Garcia, J. M., & Asunda, P. (2024, June). Mixed reality as a teaching tool for improving spatial visualization in engineering students. Paper presented at 2024 ASEE Annual Conference & Exposition, Portland, Oregon. 10.18260/1-2--47781
3. Atit, K., Power, J. R., Veurink, N., Uttal, D. H., Sorby, S., Panther, G., Msall, C., Fiorella, L., & Carr, M. (2020). Examining the role of spatial skills and mathematics motivation on middle school mathematics achievement. *International Journal of STEM Education*, 7(1). <https://doi.org/10.1186/s40594-020-00234-3>
4. Atit, K., Power, J. R., Pigott, T., Lee, J., Geer, E. A., Uttal, D. H., Ganley, C. M., & Sorby, S. A. (2021). Examining the relations between spatial skills and mathematical performance: A meta-analysis. *Psychonomic Bulletin & Review*, 29. <https://doi.org/10.3758/s13423-021-02012-w>
5. Bairaktarova, D., Reyes, M., Nassr, N., & Carlton, D. T. (2015, June). Spatial skills development of engineering students: identifying instructional tools to incorporate into existing curricula. Paper presented at 2015 ASEE Annual Conference & Exposition, Seattle, Washington. 10.18260/p.24726
6. Charlesworth, P., Drummer, T., Hungwe, K., & Sorby, S. (2005, June). Developing 3 D spatial visualization skills for non engineering students. Paper presented at 2005 Annual Conference, Portland, Oregon. 10.18260/1-2—15370
7. De Rosa, A. J., & Fontaine, M. (2019, November). Additional benefits of spatial-visualization skills workshops: assessing improvements in student self-efficacy and other affective skills. Paper presented at 2019 Fall Mid Atlantic States Conference, New York, New York. <https://peer.asee.org/33800>
8. Dimitriu, D. G. (2016, June). A new way to help students improve 3-D visualization. Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana. 10.18260/p.26194
9. Dimitriu, D. G., & Dimitriu, D. C. (2020, June). A simple method allowing students to improve their 3-D visualization skills. Paper presented at 2020 ASEE Virtual Annual Conference Content Access, Virtual Online. 10.18260/1-2—34050
10. Di, X., & Zheng, X. (2022). A meta-analysis of the impact of virtual technologies on students' spatial ability. *Educational Technology Research and Development*, 70(1), 73–98. <https://doi.org/10.1007/s11423-022-10082-3>
11. Dominguez, M. G., Martin-Gutierrez, J., & Roca, C. (2013, June). Tools, methodologies and motivation to improve spatial skill on engineering students. Paper presented at 2013 ASEE Annual Conference & Exposition, Atlanta, Georgia. 10.18260/1-2—22638

12. Dong, Y., & El-Sayed, J. A. (2011, June). Engage engineering and science students by improving their spatial visualization skills. Paper presented at 2011 ASEE Annual Conference & Exposition, Vancouver, BC. 10.18260/1-2—17848
13. Endres, M., Fansher, M., Shah, P., & Weimer, W. (2021). To read or to rotate? comparing the effects of technical reading training and spatial skills training on novice programming ability. *Proceedings of the 29th ACM Joint Meeting on European Software Engineering Conference and Symposium on the Foundations of Software Engineering*. <https://doi.org/10.1145/3468264.3468583>
14. Gurganus, J. R., Hill, E., & Spence, A. M. (2018, June). The effect of the project lead the way program on students' spatial visualization skills (Evaluation). Paper presented at 2018 ASEE Annual Conference & Exposition, Salt Lake City, Utah. 10.18260/1-2—31089
15. Harris, D., Lowrie, T., Logan, T., & Hegarty, M. (2020). Spatial reasoning, mathematics, and gender: Do spatial constructs differ in their contribution to performance? *British Journal of Educational Psychology*, 91(1), 409–441. <https://doi.org/10.1111/bjep.12371>
16. Herawati, H., & Hariyani, M. (2024). Spatial thinking ability in elementary school. *Pionir Jurnal Pendidikan*, 13(1). <https://doi.org/10.22373/pjp.v13i1.23002>
17. Hawes, Z. C. K., Gilligan-Lee, K. A., & Mix, K. S. (2022). Effects of spatial training on mathematics performance: A meta-analysis. *Developmental Psychology*, 58(1), 112–137. <https://doi.org/10.1037/dev0001281>
18. LeBow, V., Bernhardt-Barry, M. L., & Datta, J. (2018, June). Improving spatial visualization abilities using 3D printed blocks. Paper presented at 2018 ASEE Annual Conference & Exposition, Salt Lake City, Utah. 10.18260/1-2—30634
19. Margulieux, L. E. (2020, February). Spatial encoding strategy theory: the relationship between spatial skill and STEM achievement. *ACM Inroads*, 11(1), 65–75. <https://doi.org/10.1145/3381891>
20. Parkinson, J., Cutts, Q. (2020, June). The effect of a spatial skills training course in introductory computing. Paper presented at ITiCSE '20: Proceedings of the 2020 ACM Conference on Innovation and Technology in Computer Science Education, 439 - 445. <https://doi.org/10.1145/3341525.3387413>
21. Rahmawati, Y., Dianhar, H., & Arifin, F. (2021). Analyzing students' spatial abilities in chemistry learning using 3D virtual representation. *Education Sciences*, 11(4), 185. <https://doi.org/10.3390/educsci11040185>
22. Schwartz, E., Philpot, T., & Hall, R. (2006, June). A Qualitative exploration Of engineering students' 3 D visualization processing. Paper presented at 2006 Annual Conference & Exposition, Chicago, Illinois. 10.18260/1-2—1122
23. Šafhalter, A., Glodež, S., Šorgo, A., & Ploj Virtič, M. (2020). Development of spatial thinking abilities in engineering 3D modeling course aimed at lower secondary students. *International Journal of Technology and Design Education*.

24. Sorby, S., & Veurink, N. (2010, June). Are the visualization skills of first year engineering students changing? Paper presented at 2010 Annual Conference & Exposition, Louisville, Kentucky. 10.18260/1-2—16026
25. Tseng, T., & Yang, M. (2011, June). The role of spatial-visual skills in a project-based engineering design course. Paper presented at 2011 ASEE Annual Conference & Exposition, Vancouver, BC. 10.18260/1-2—18466
26. Tumkor, S., & de Vries, R. H. (2015, June). Enhancing spatial visualization skills in engineering drawing courses. Paper presented at 2015 ASEE Annual Conference & Exposition, Seattle, Washington. 10.18260/p.24001
27. Viswanathan, V. K., Mirza, S. H., Nayak, C. R., & Calhoun, M. (2020, June). Evaluation of a puzzle-based virtual platform for improving spatial visualization skills in engineering freshmen. Paper presented at 2020 ASEE Virtual Annual Conference Content Access, Virtual Online. 10.18260/1-2—34602
28. Veurink, N. L., & Hamlin, A. (2011, June). Spatial visualization skills: impact on confidence and success in an engineering curriculum. Paper presented at 2011 ASEE Annual Conference & Exposition, Vancouver, BC. 10.18260/1-2--18591
29. Yue, J. (2002, June). Spatial visualization skills at various educational levels. Paper presented at 2002 Annual Conference, Montreal, Canada. 10.18260/1-2—11098

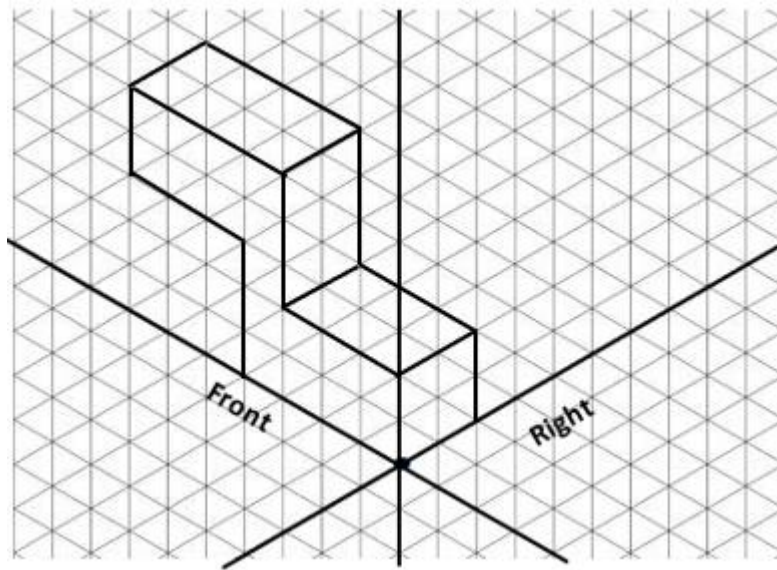
Appendix A

Spatial Pre Test

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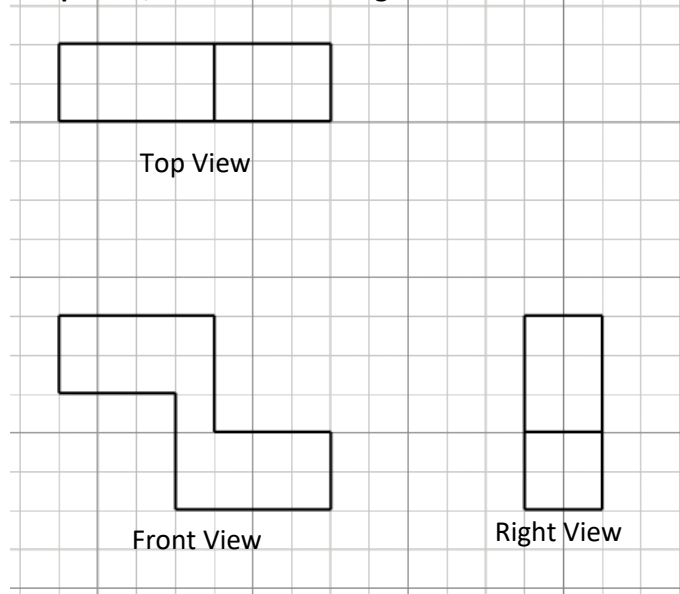
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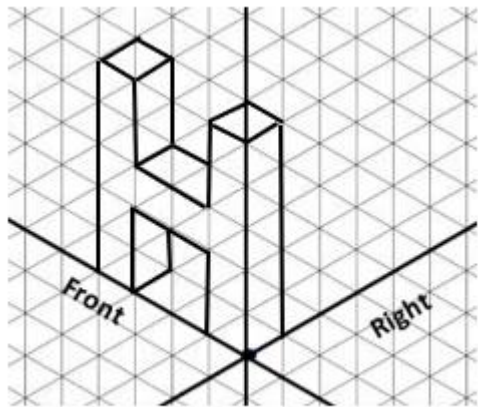


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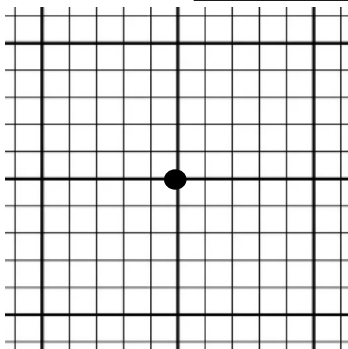


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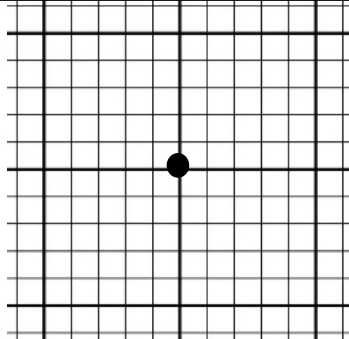


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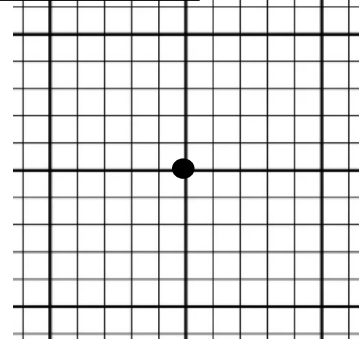
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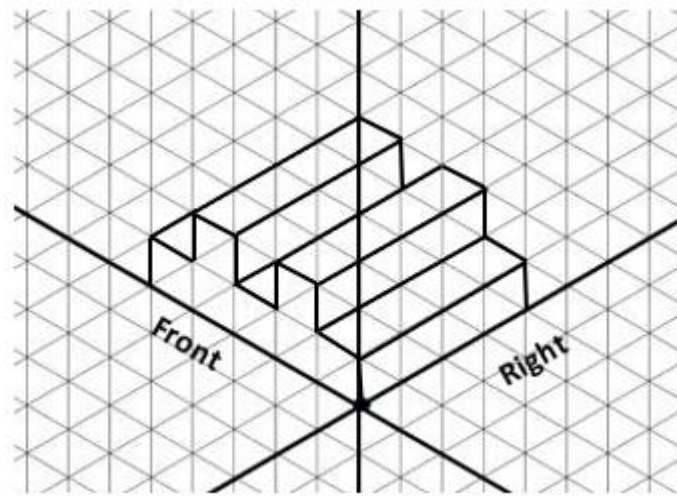


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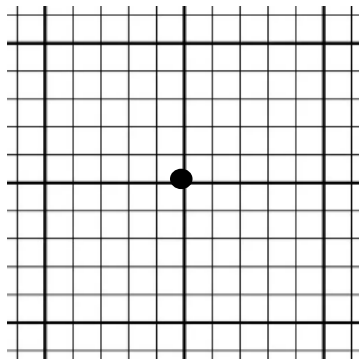
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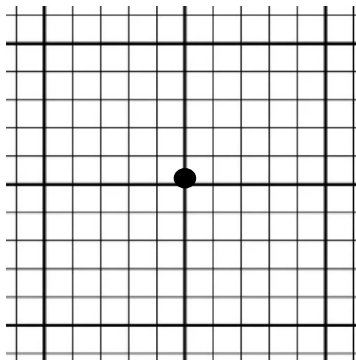


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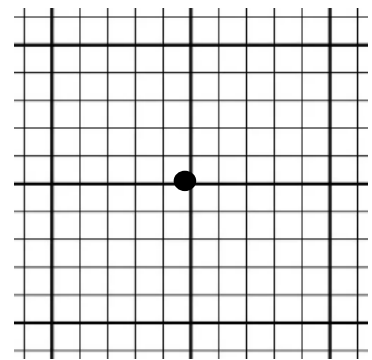
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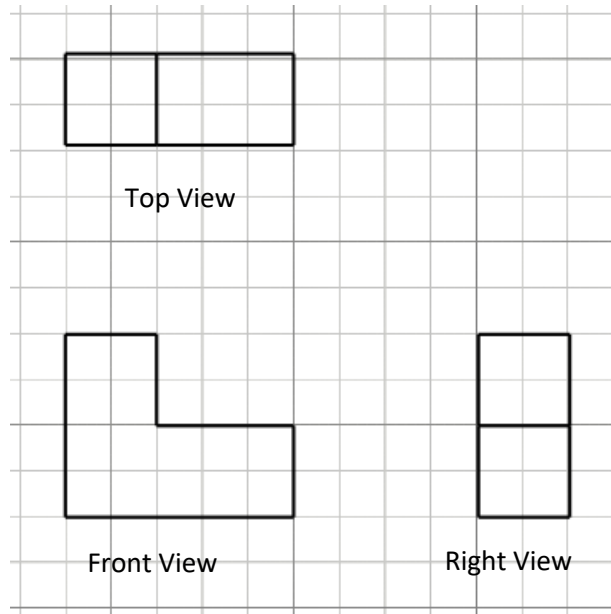


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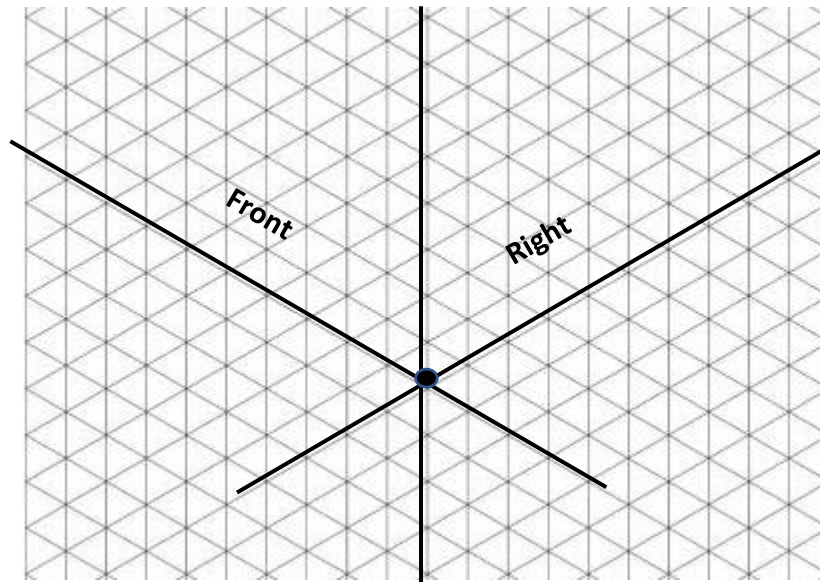


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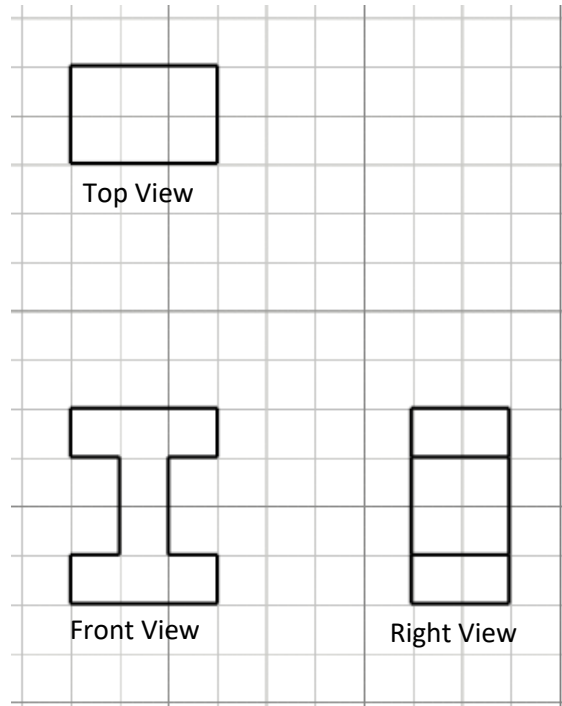
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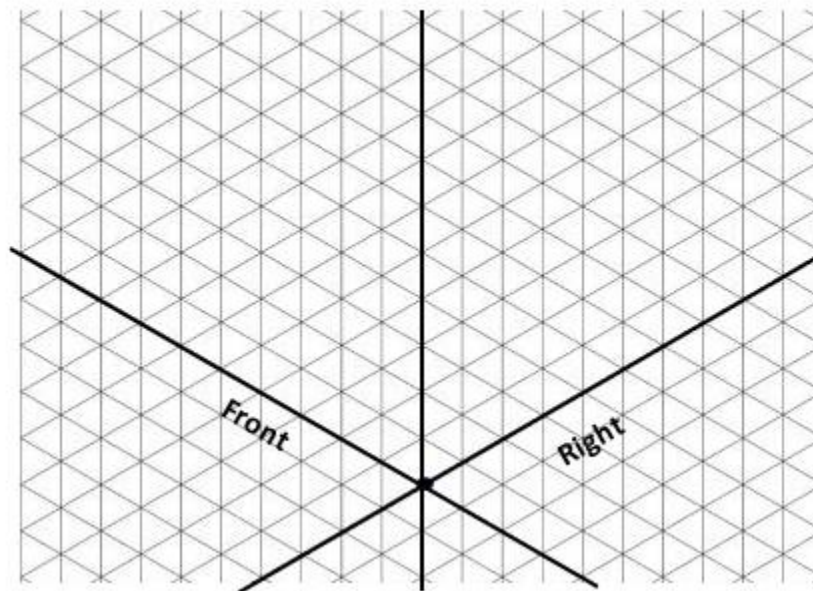
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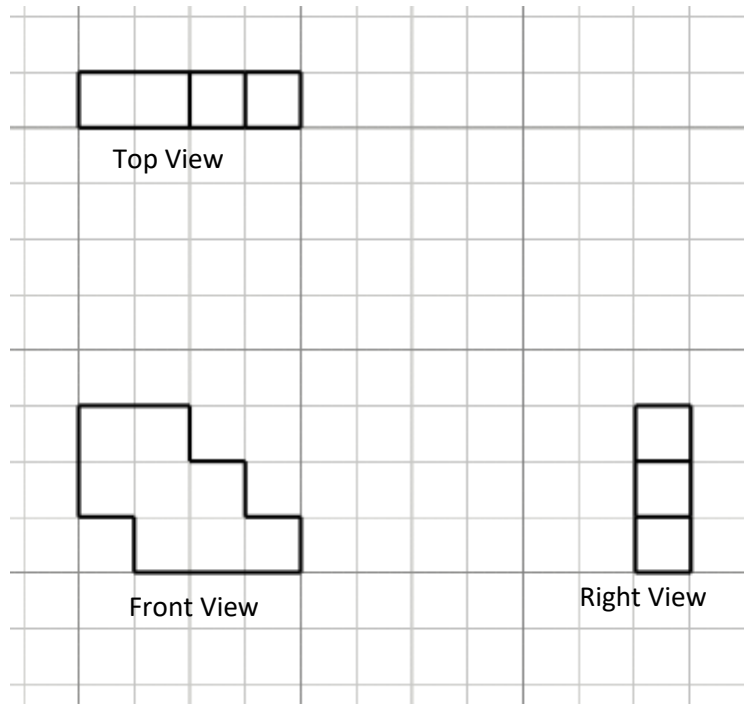
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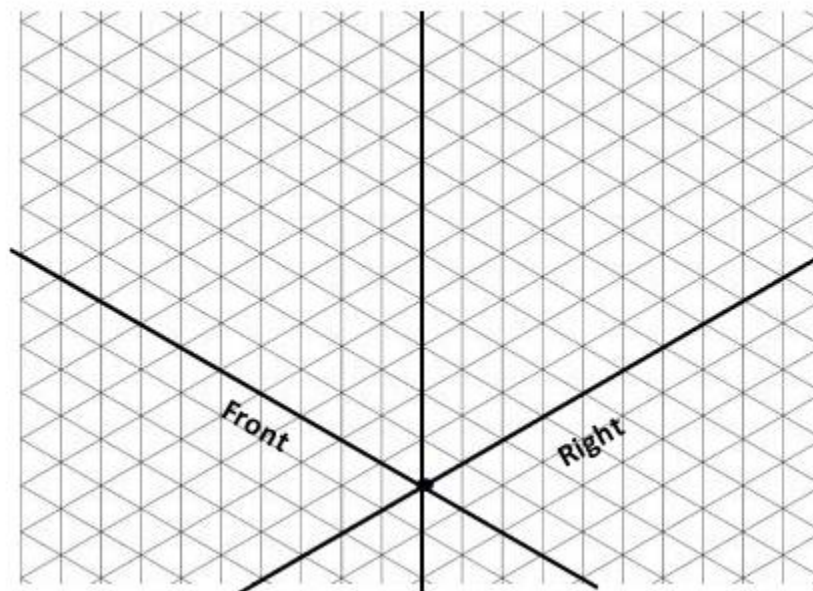
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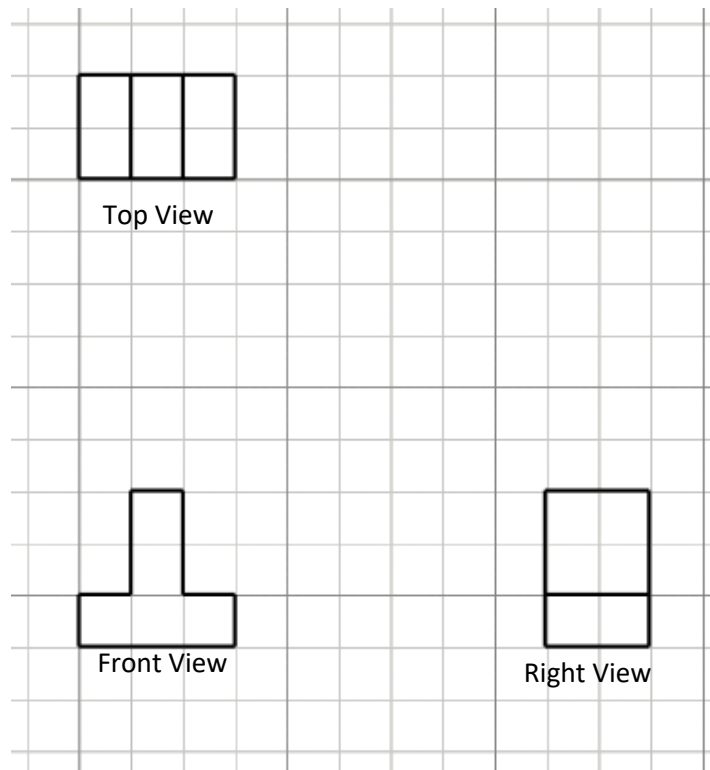
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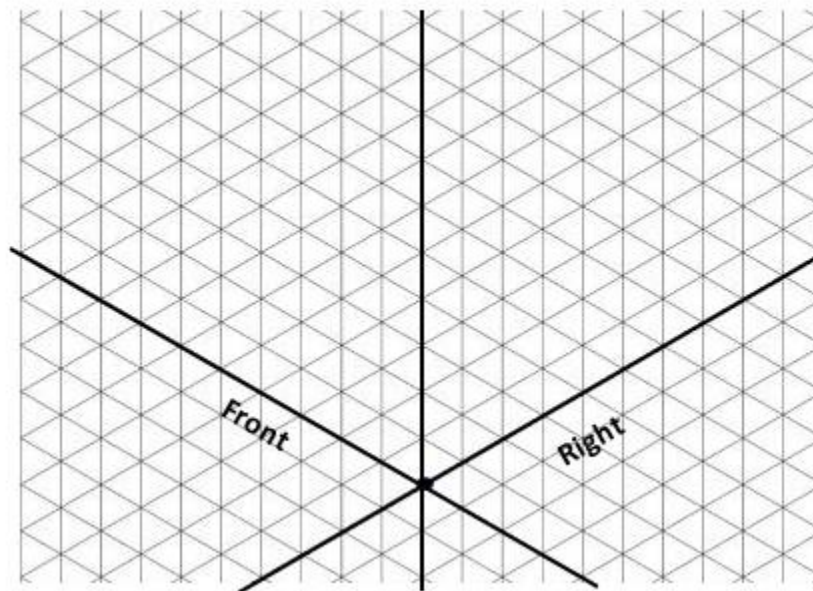
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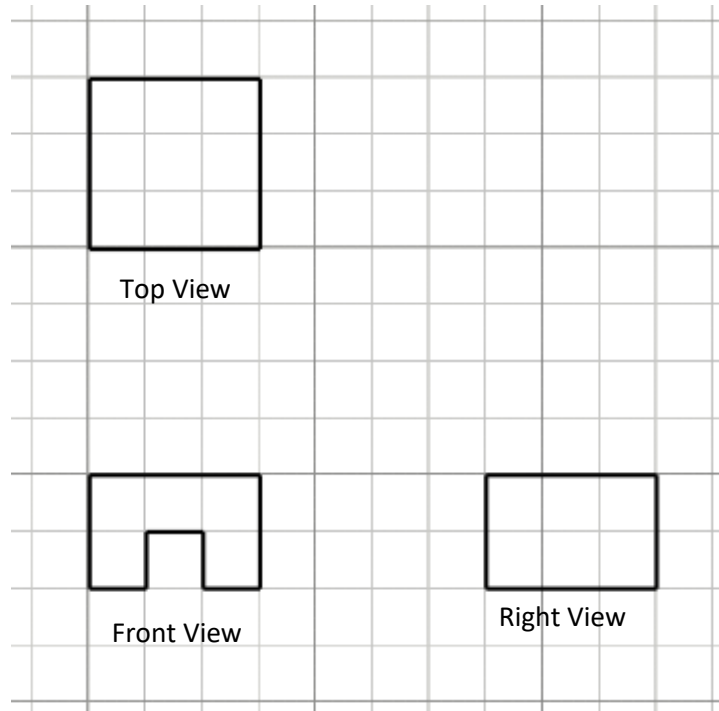
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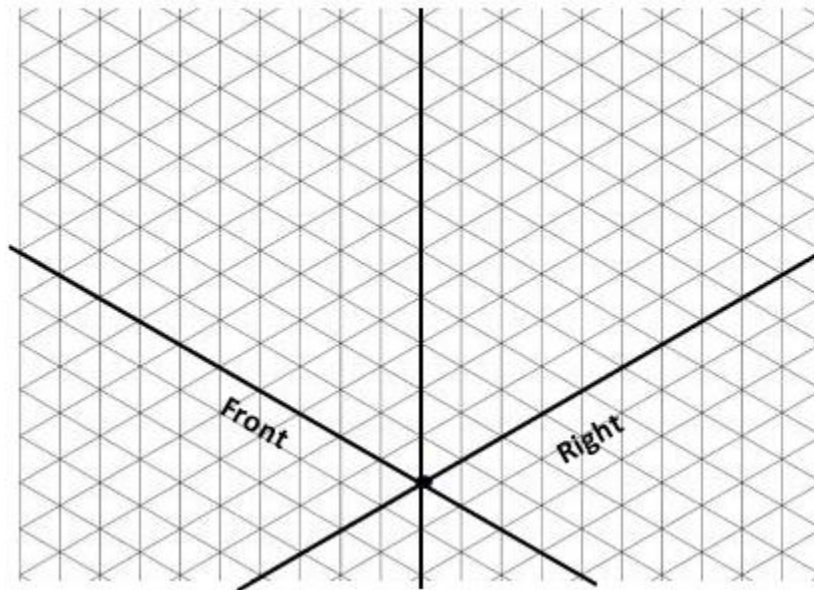
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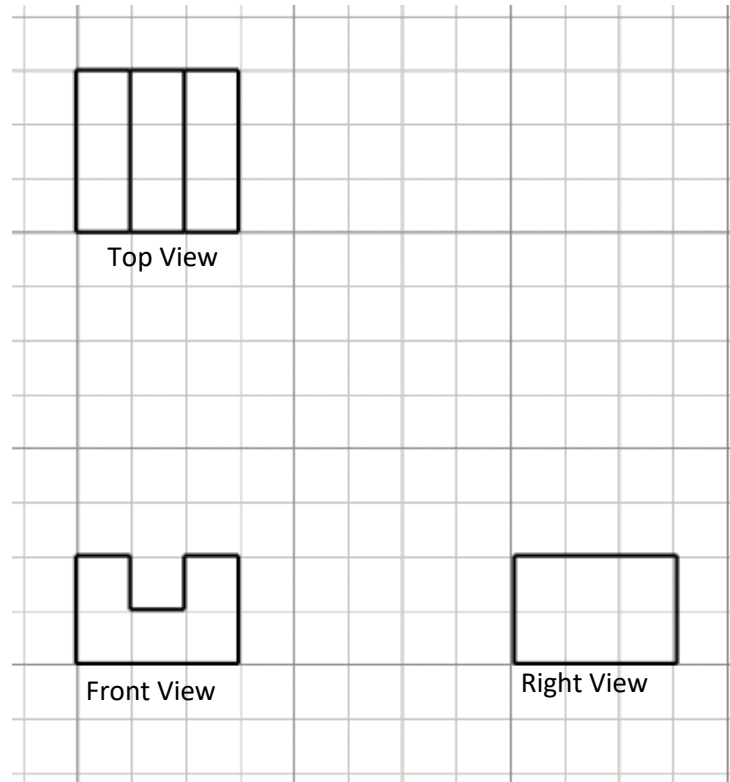
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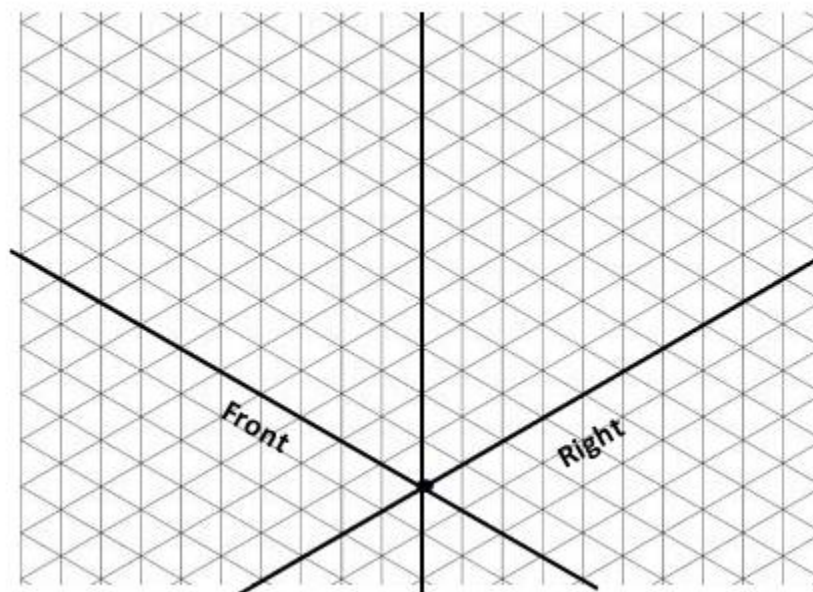
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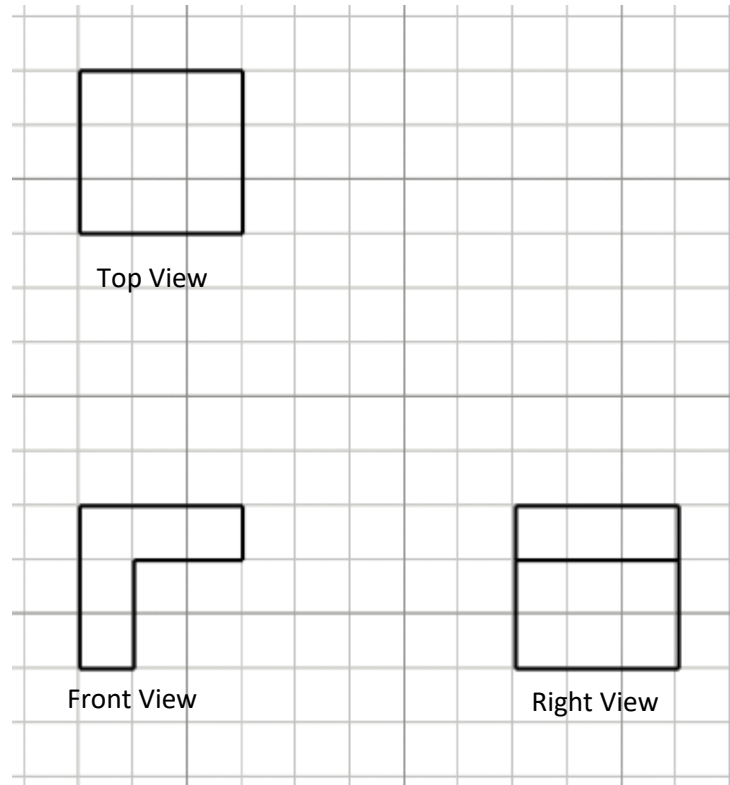
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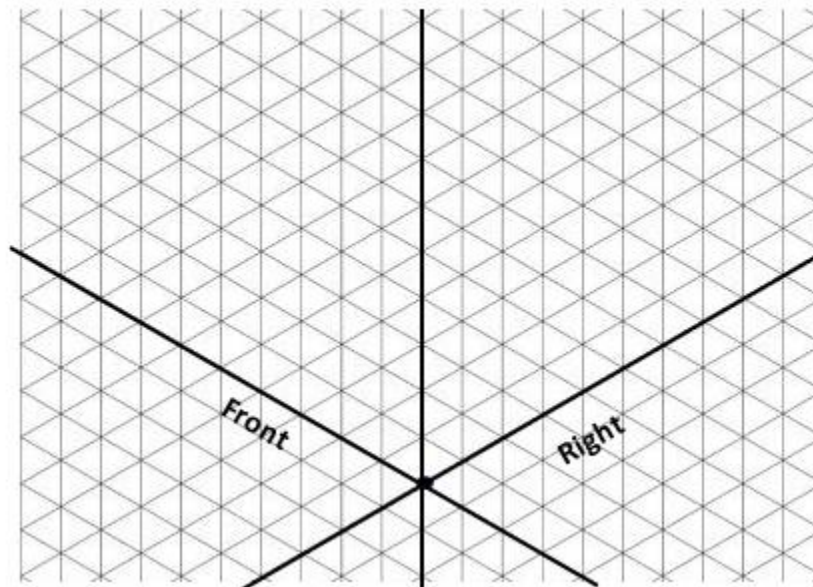
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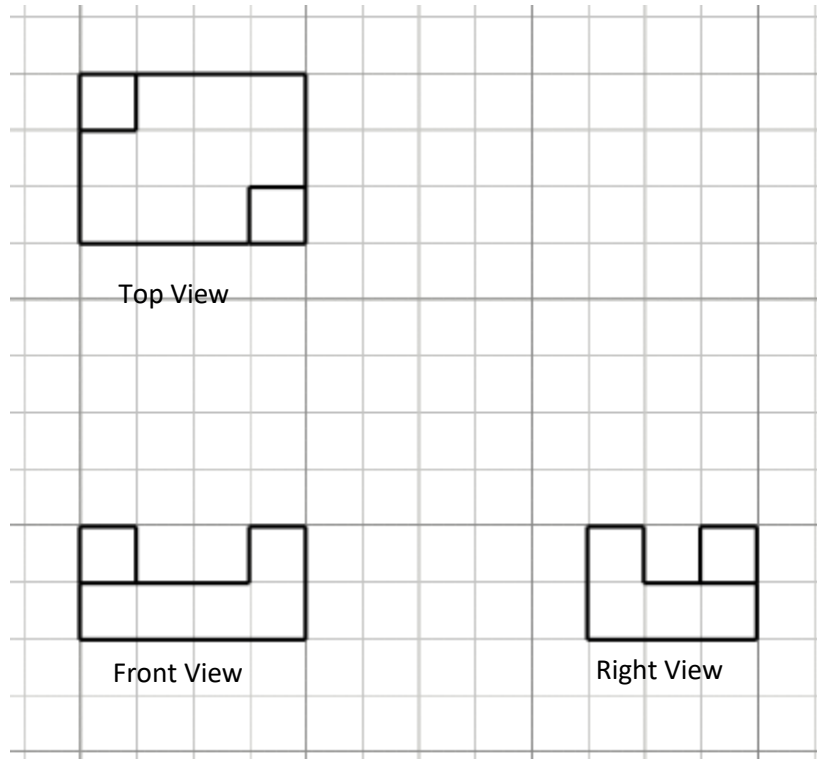
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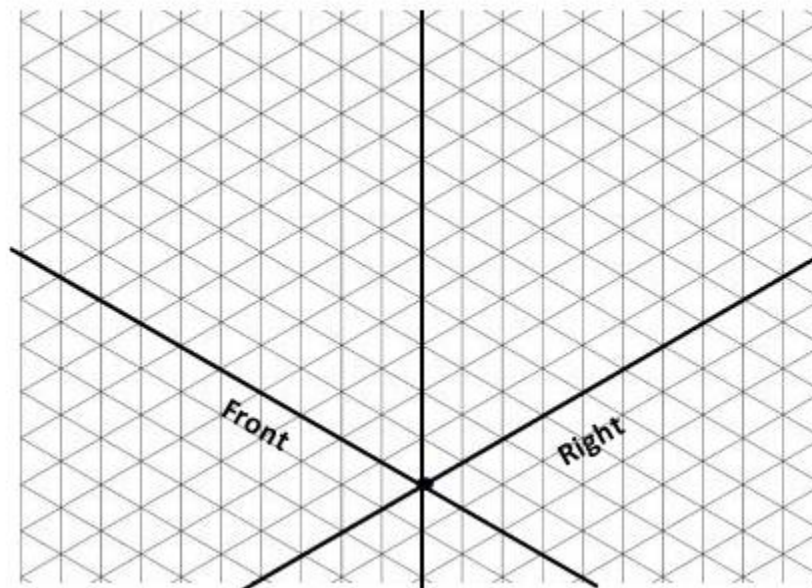
Draw Isometric View from Top View, Front View and Right View



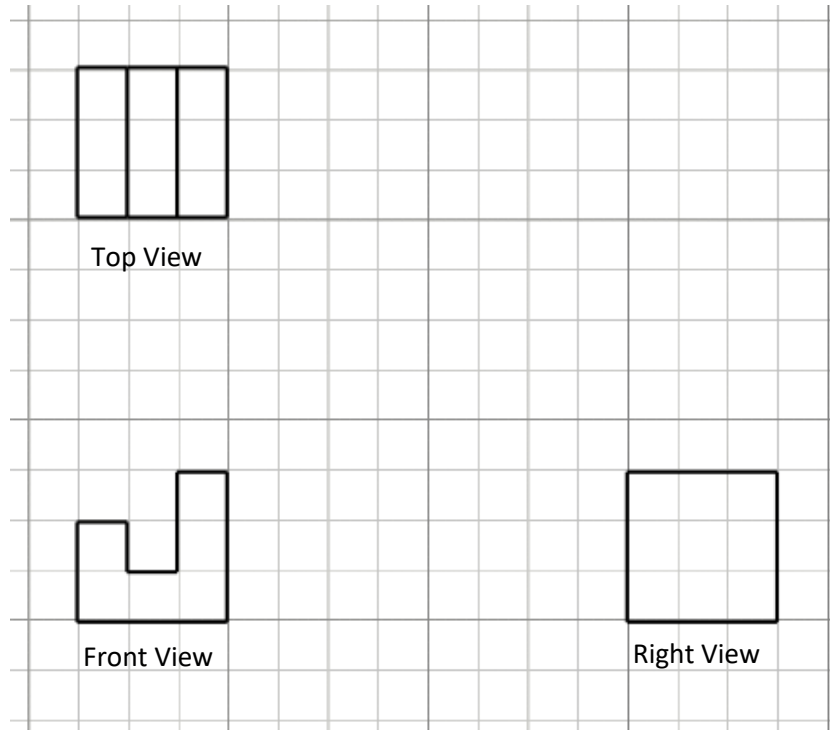
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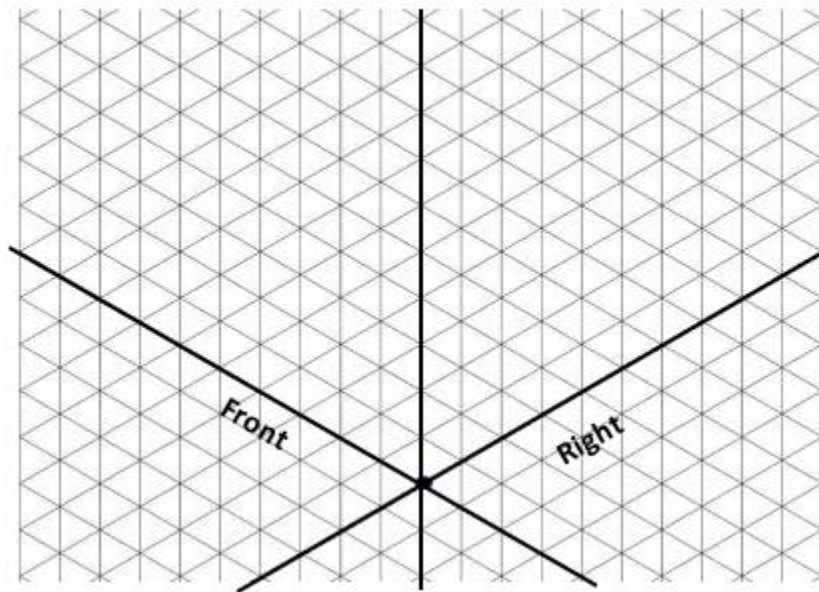
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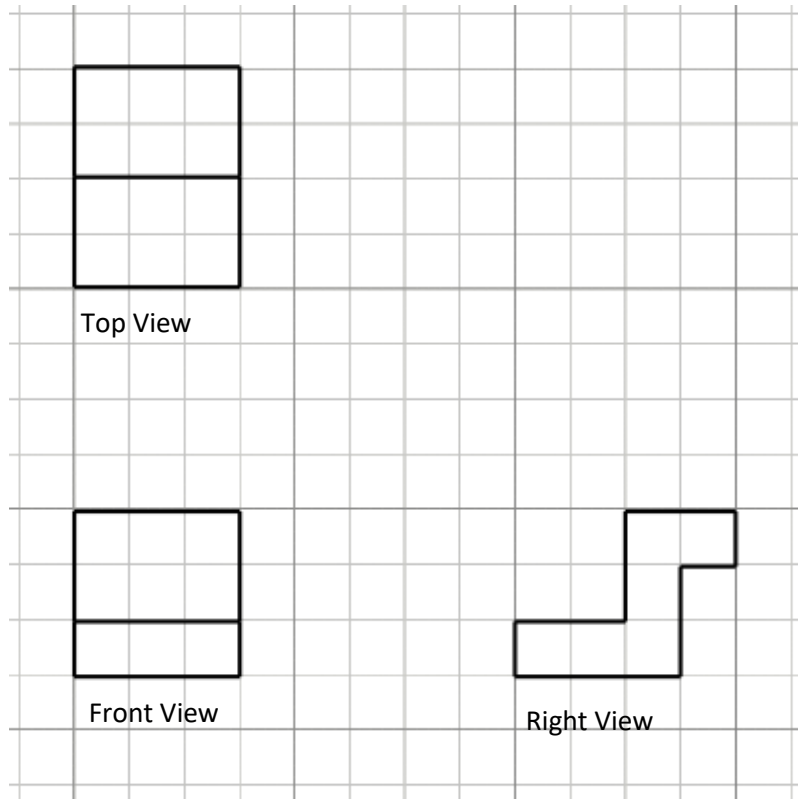
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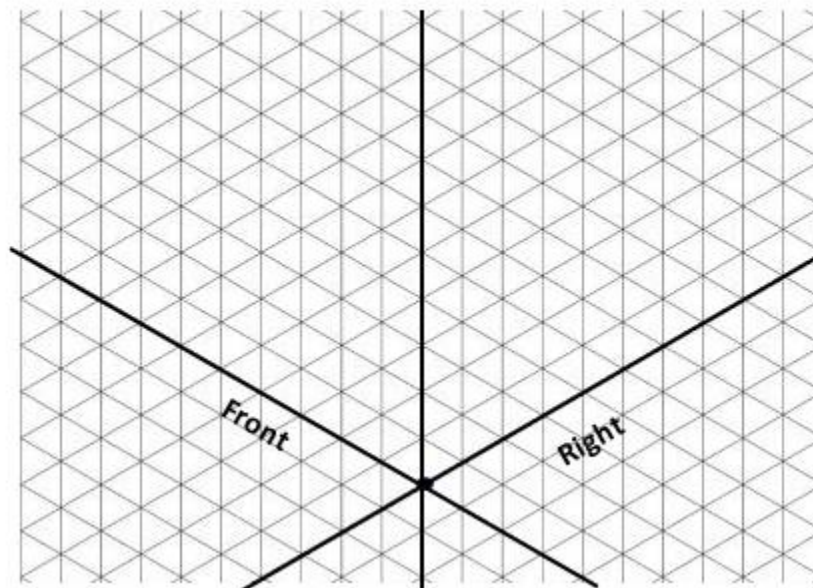
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Questions No. 12



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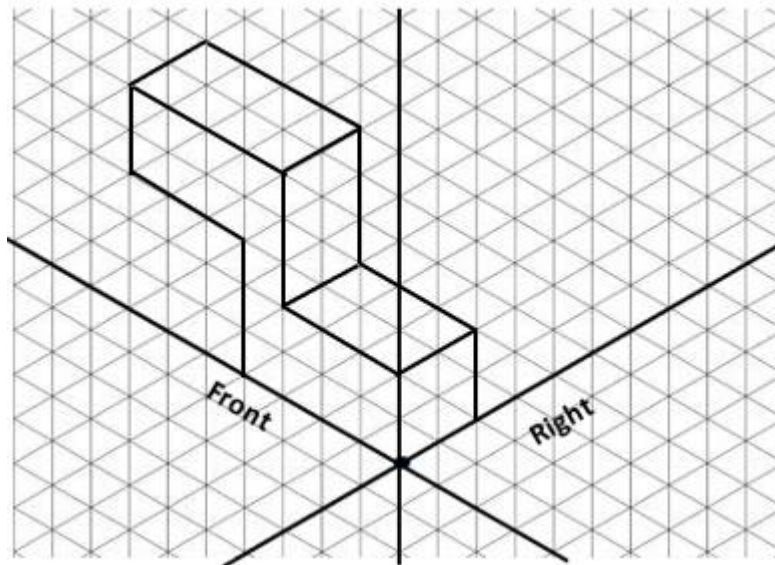


Appendix B
Spatial Post Test

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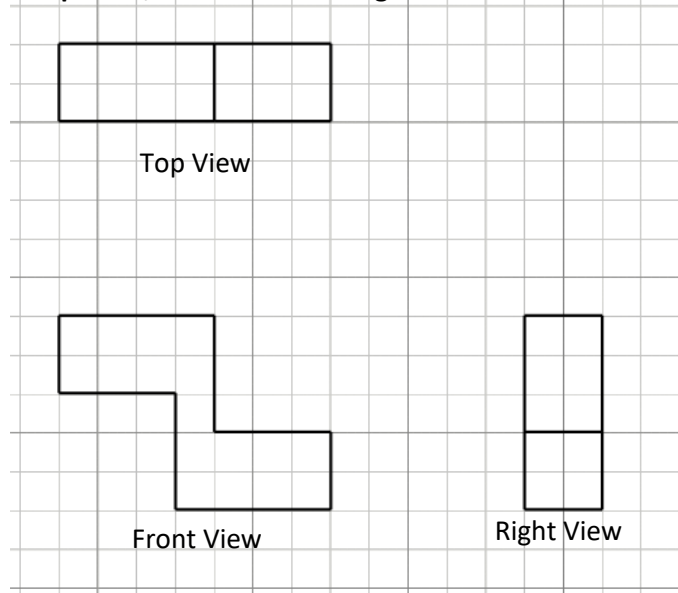
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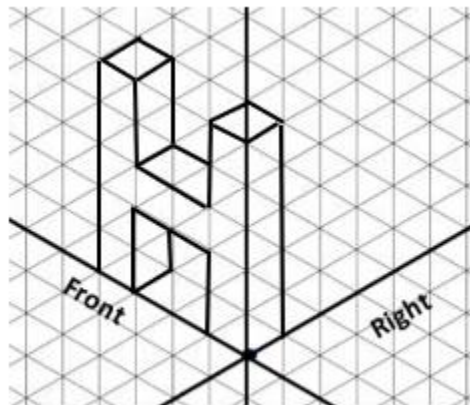


Isometric View

Draw Top View, Front View and Right View from Isometric View

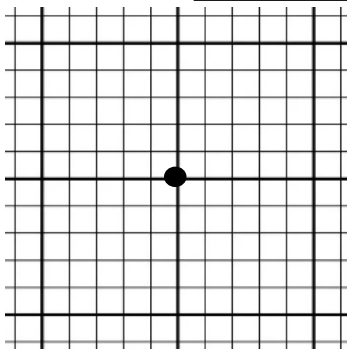


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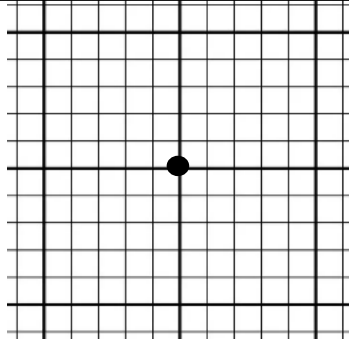


Isometric View

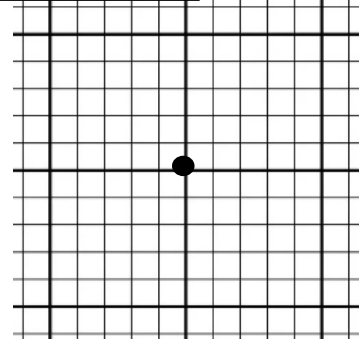
Draw Top View, Front View and Right View from Isometric View



Top View

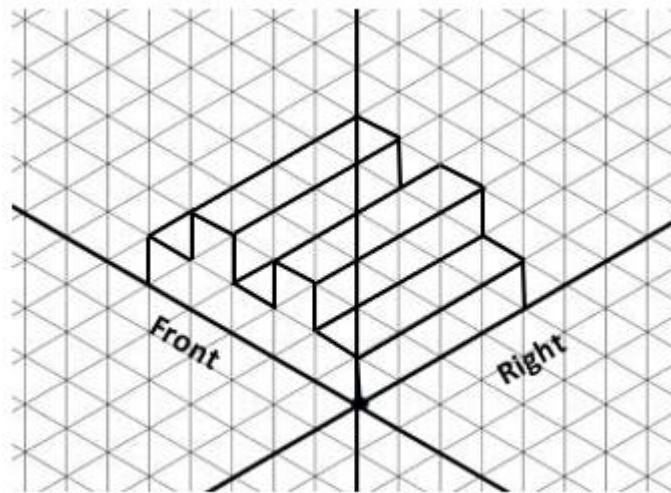


Front View



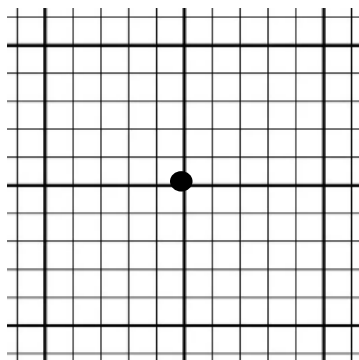
Right View

Question No. 2

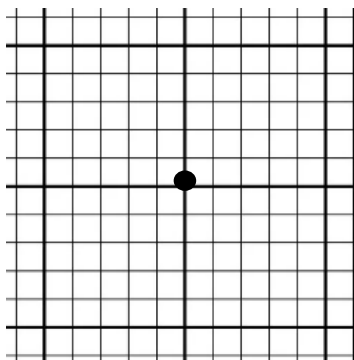


Isometric View

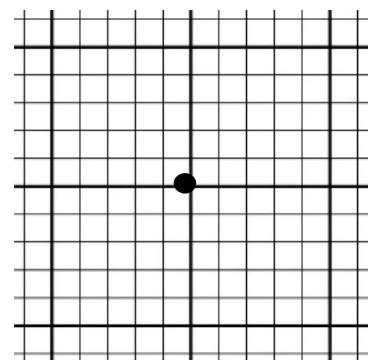
Draw Top View, Front View and Right View from Isometric View



Top View

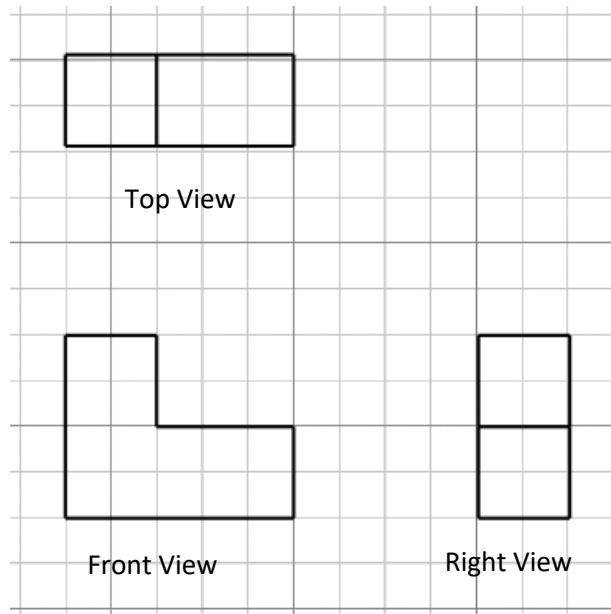


Front View

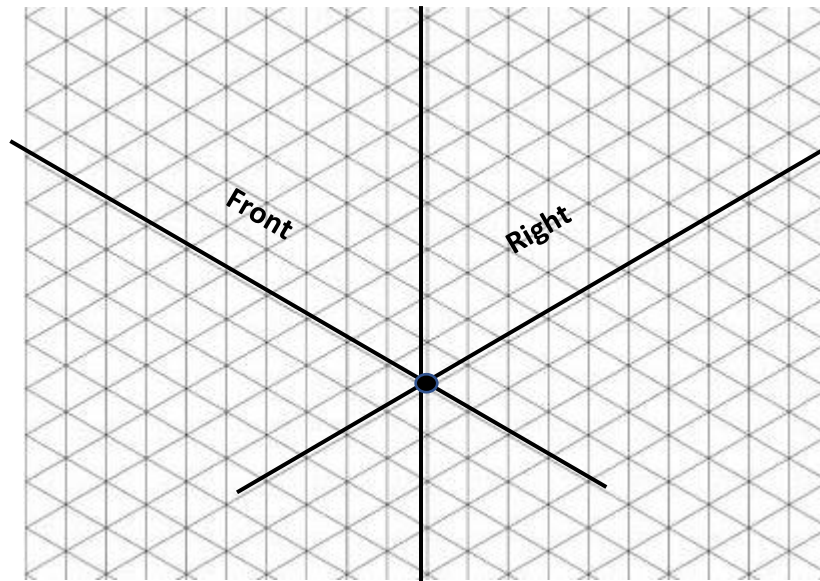


Right View

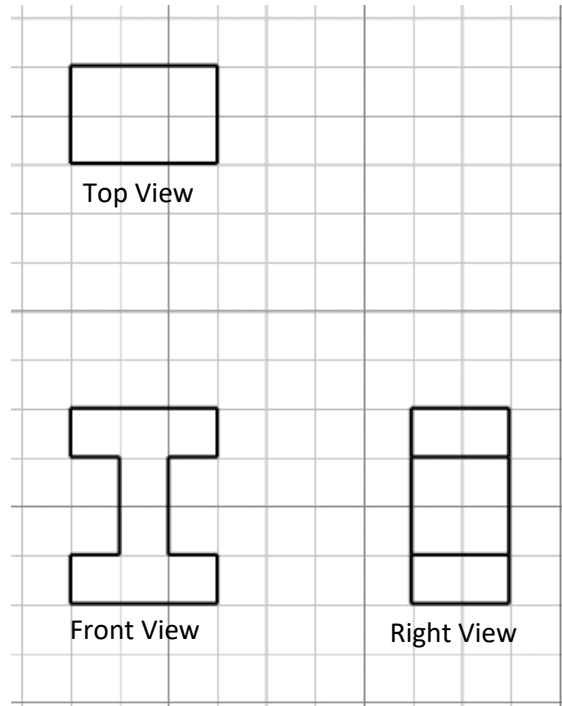
Questions No. 3



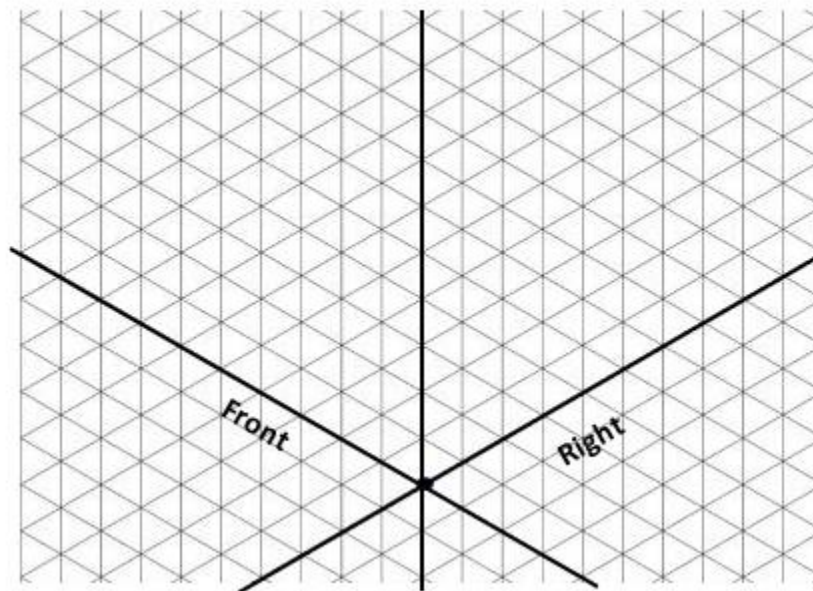
Draw Isometric View from Top View, Front View and Right View



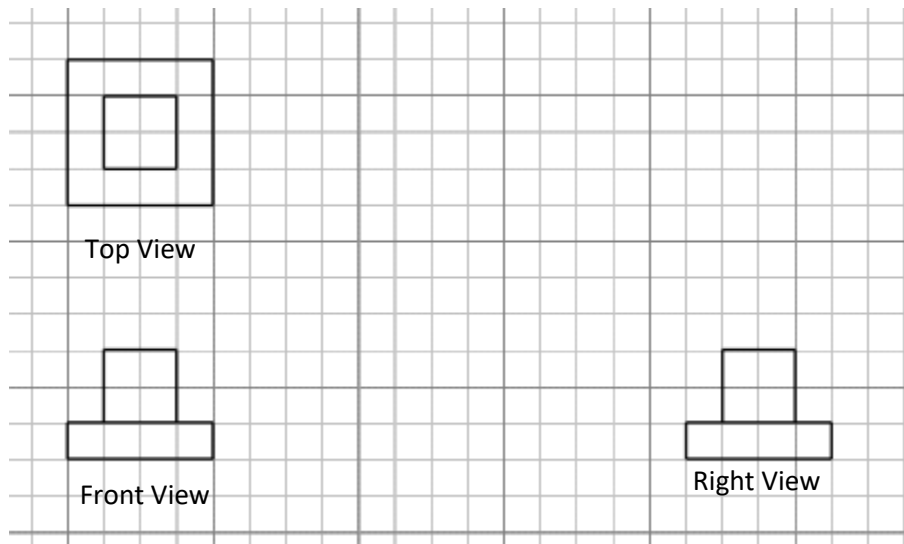
Questions No. 4



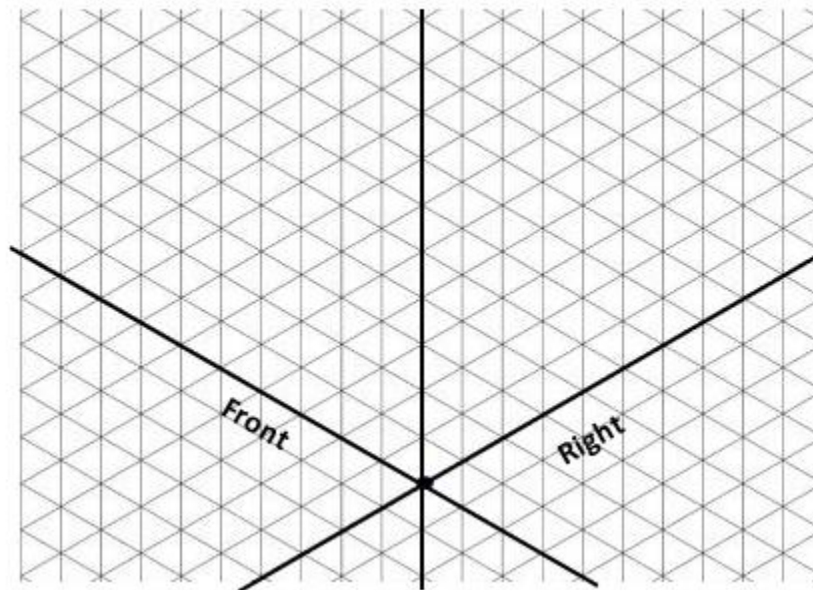
Draw Isometric View from Top View, Front View and Right View



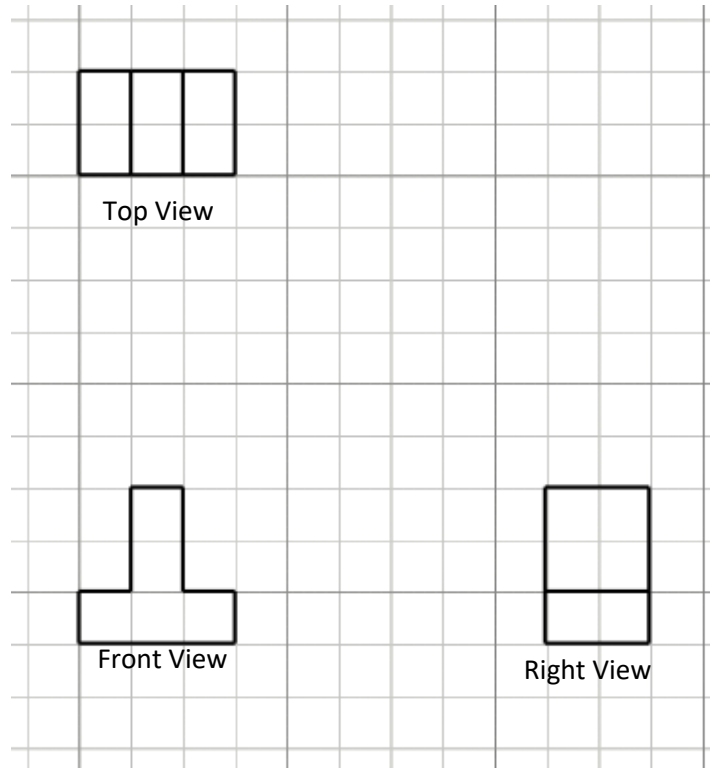
Questions No. 5



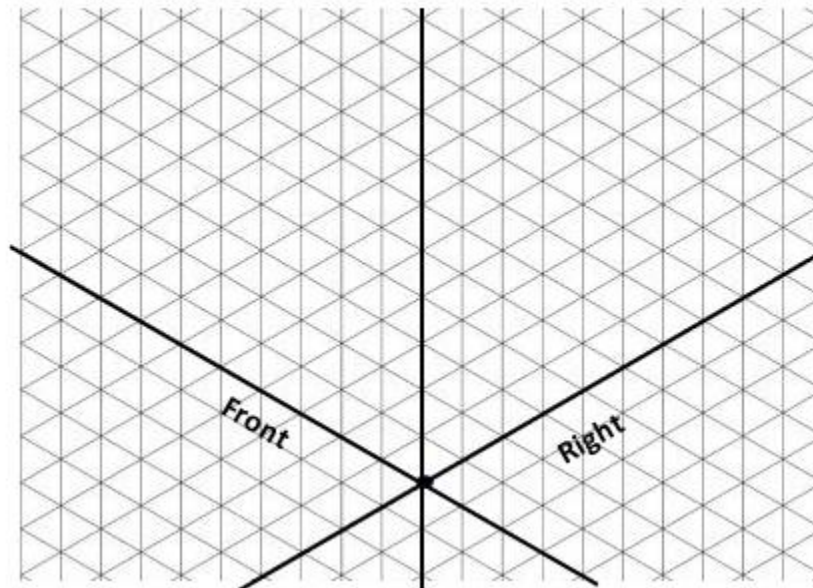
Draw Isometric View from Top View, Front View and Right View



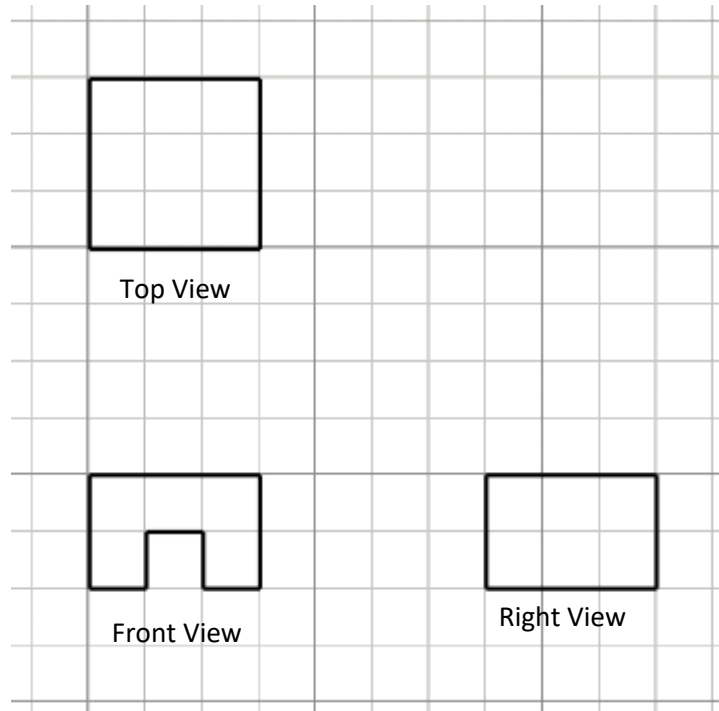
Questions No. 6



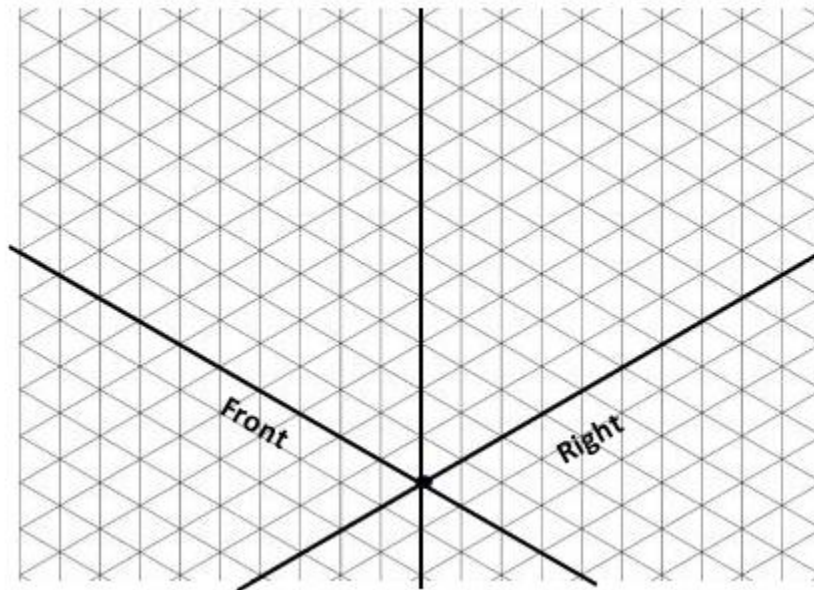
Draw Isometric View from Top View, Front View and Right View



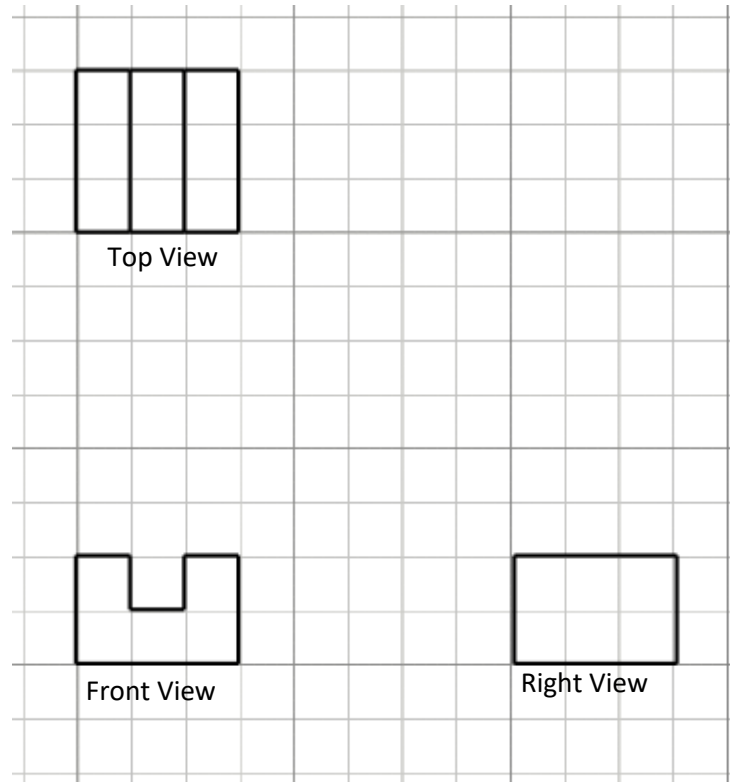
Questions No. 7



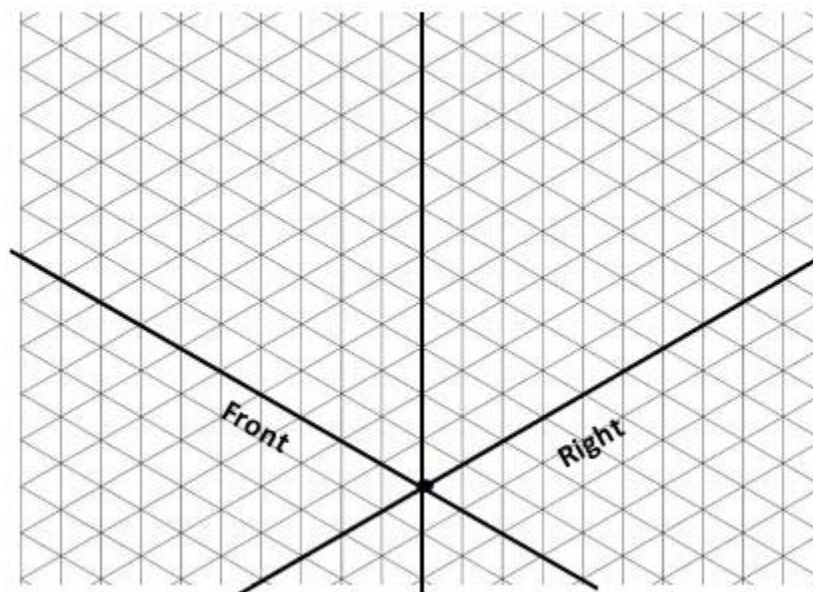
Draw Isometric View from Top View, Front View and Right View



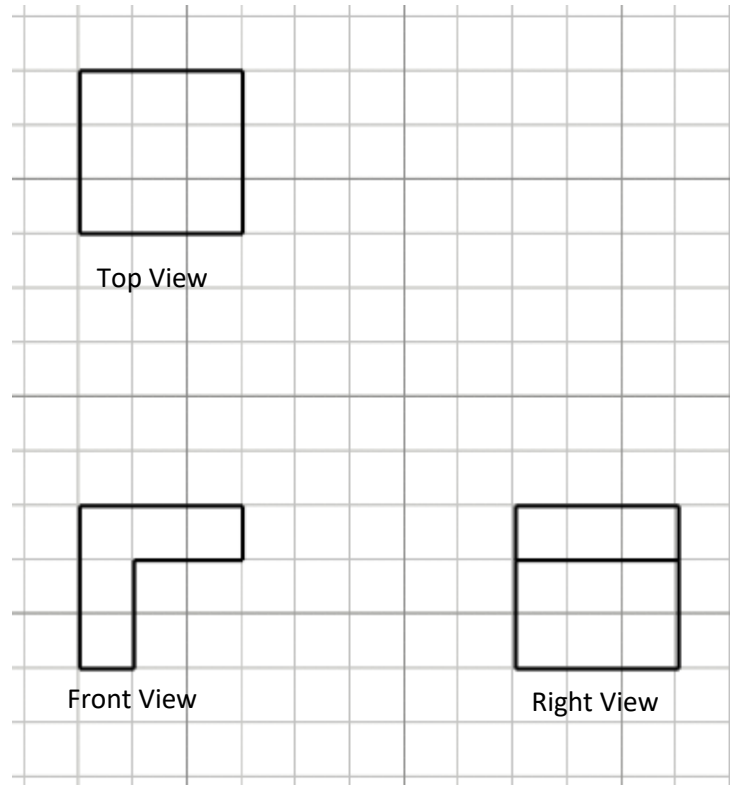
Questions No. 8



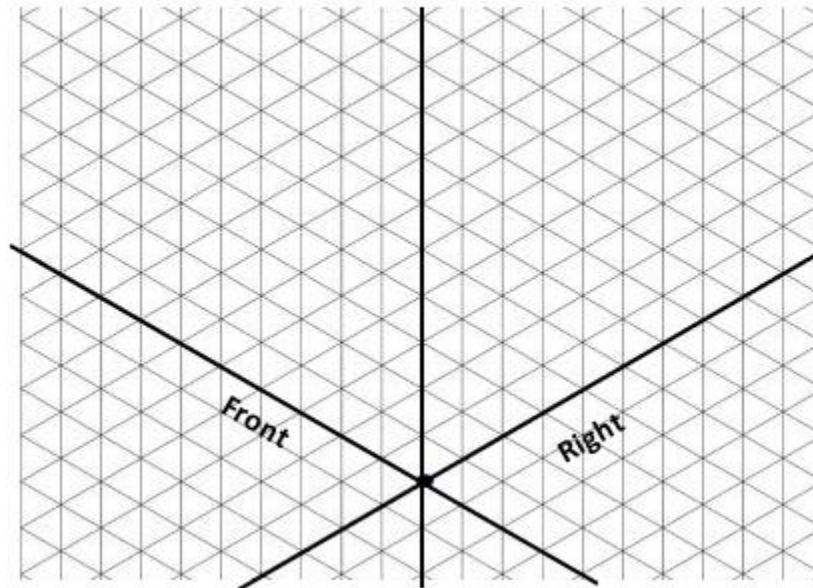
Draw Isometric View from Top View, Front View and Right View



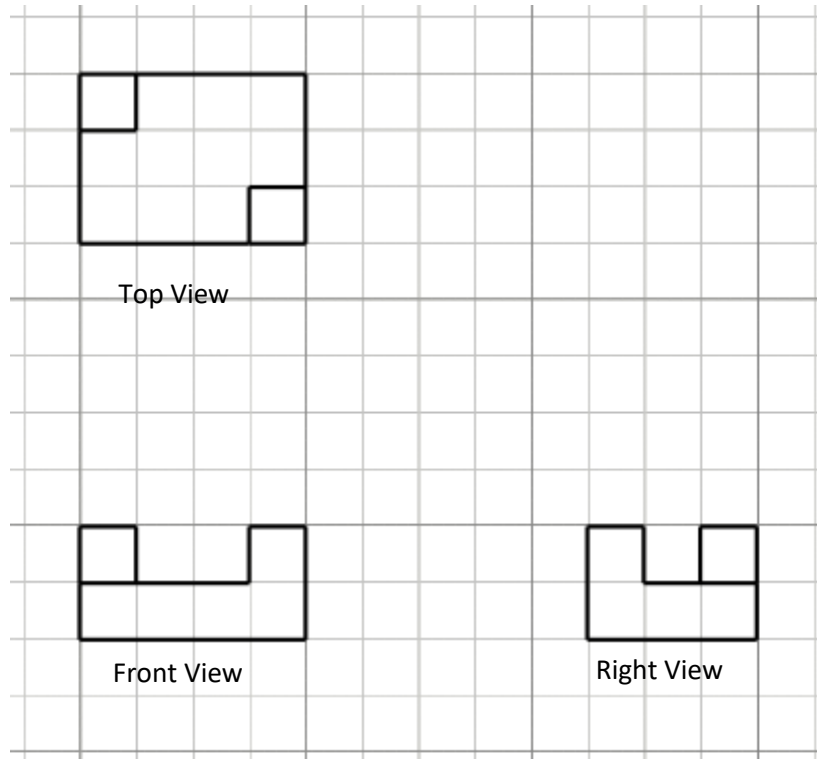
Questions No. 9



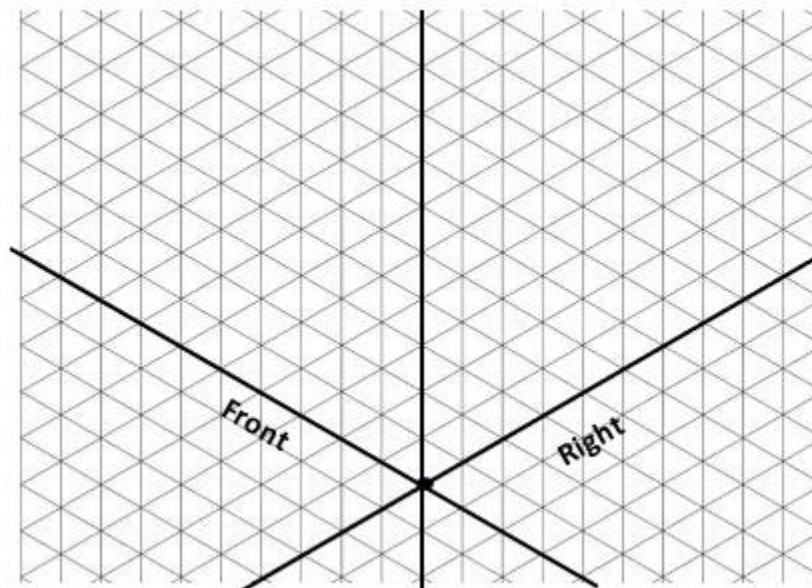
Draw Isometric View from Top View, Front View and Right View



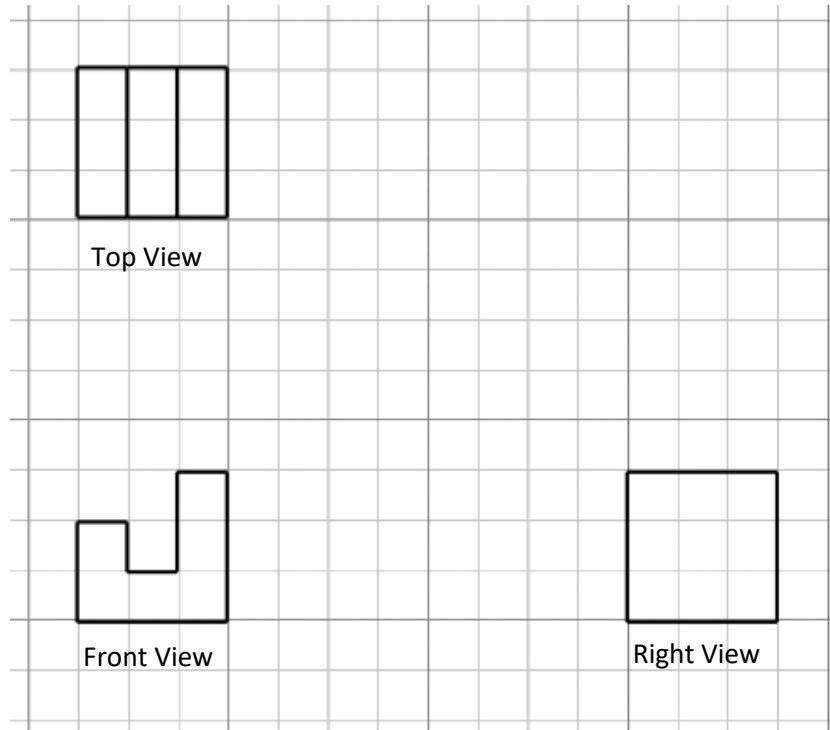
Questions No. 10



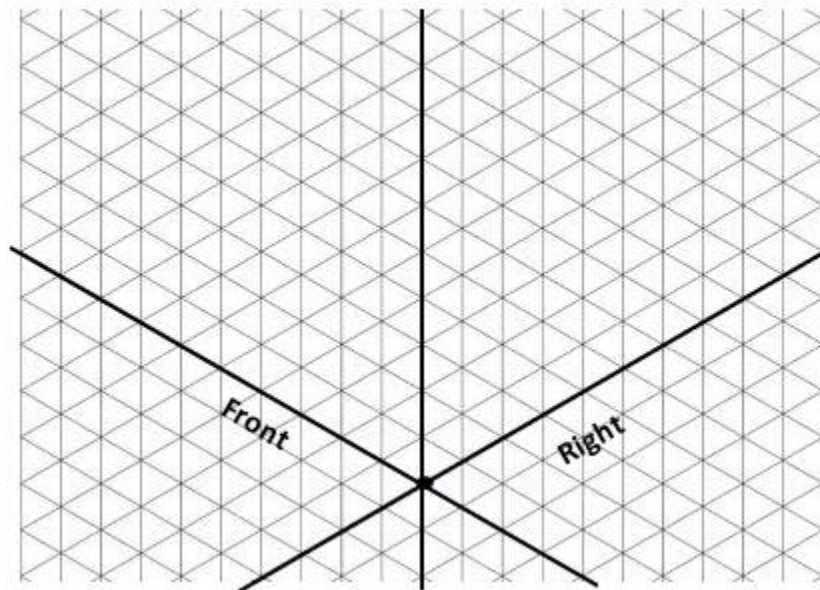
Draw Isometric View from Top View, Front View and Right View



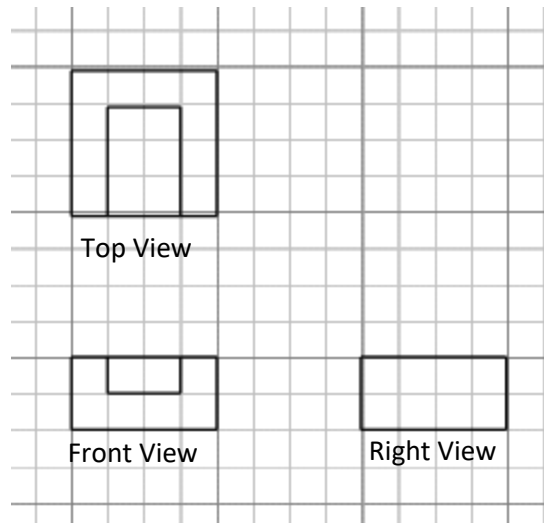
Questions No. 11



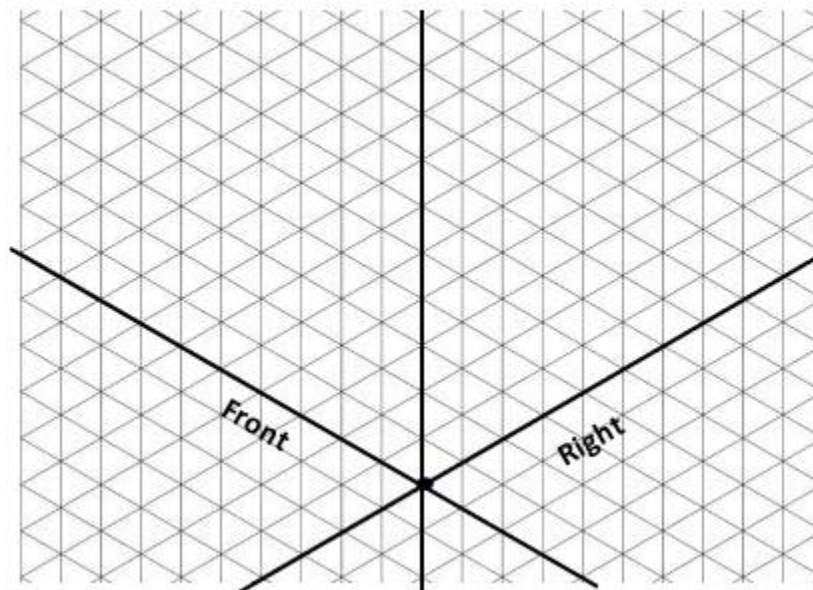
Draw Isometric View from Top View, Front View and Right View



Questions No. 12

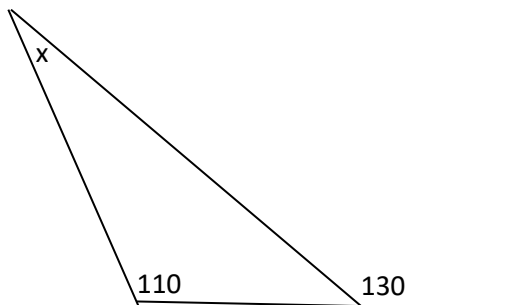


Draw Isometric View from Top View, Front View and Right View



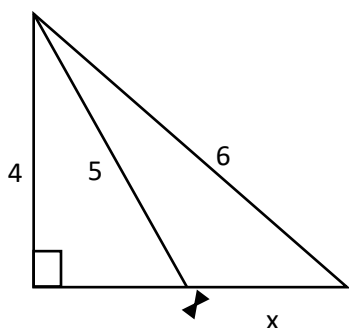
Appendix C
Math Pre Test

Question No. 1



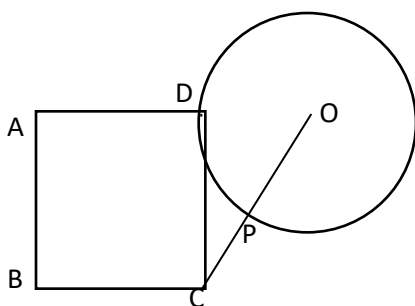
$x =$

Question No. 2



$x =$

Question No. 3



Radius of the circle = 3

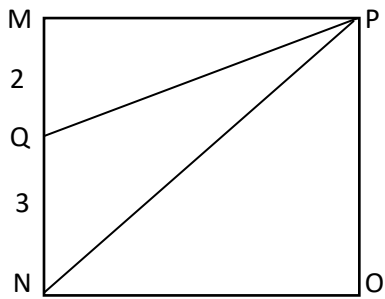
$PC = 2$

$ABCD$ is a square

DC is tangent to the circle

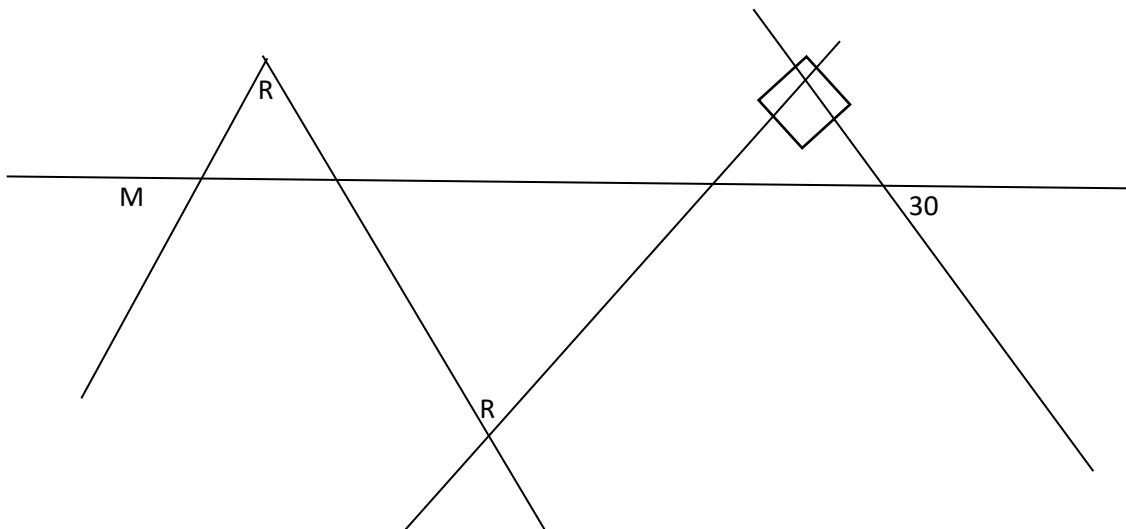
Area of the square $ABCD =$

Question No. 4



MNOP is a rectangle
 Area of triangle PQN = 9
 Area of rectangle MNOP =

Questions No. 5



M =

Appendix D
Math Post Test

NAME :

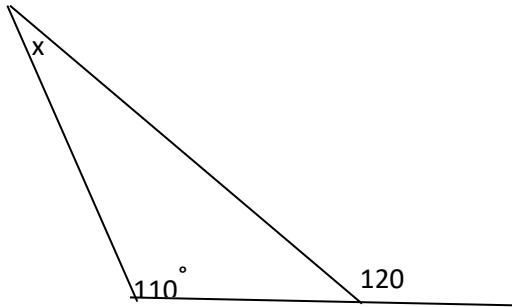
OU ID :

Math Skills Post-Assessment

You may use a calculator.

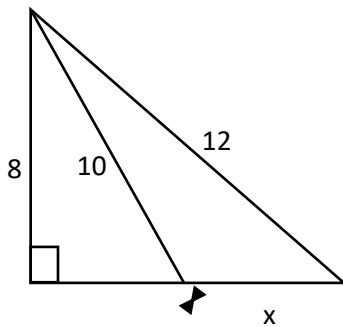
Answers may be in decimal, fraction, or root form.

Question No. 1



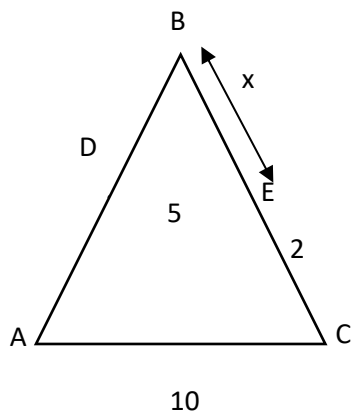
$x =$

Question No. 2



$x =$

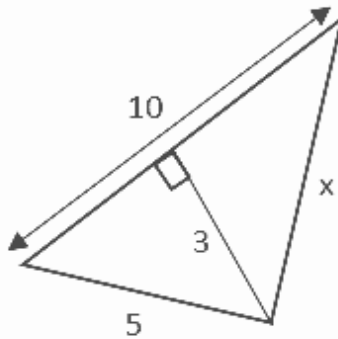
Question No. 3



$x =$

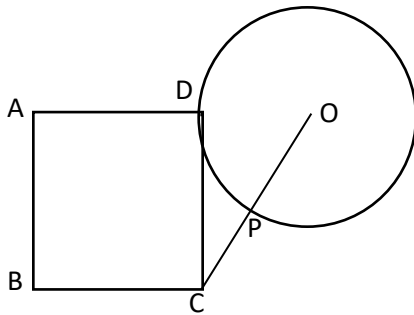
$DE \parallel AC$

Question No. 4



$X =$

Question No. 5



Radius of the circle = 5

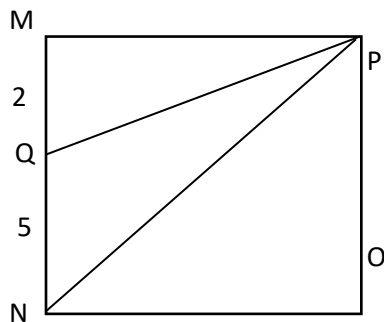
PC = 8

ABCD is a square

DC is tangent to the circle

Area of the square ABCD =

Question No. 6

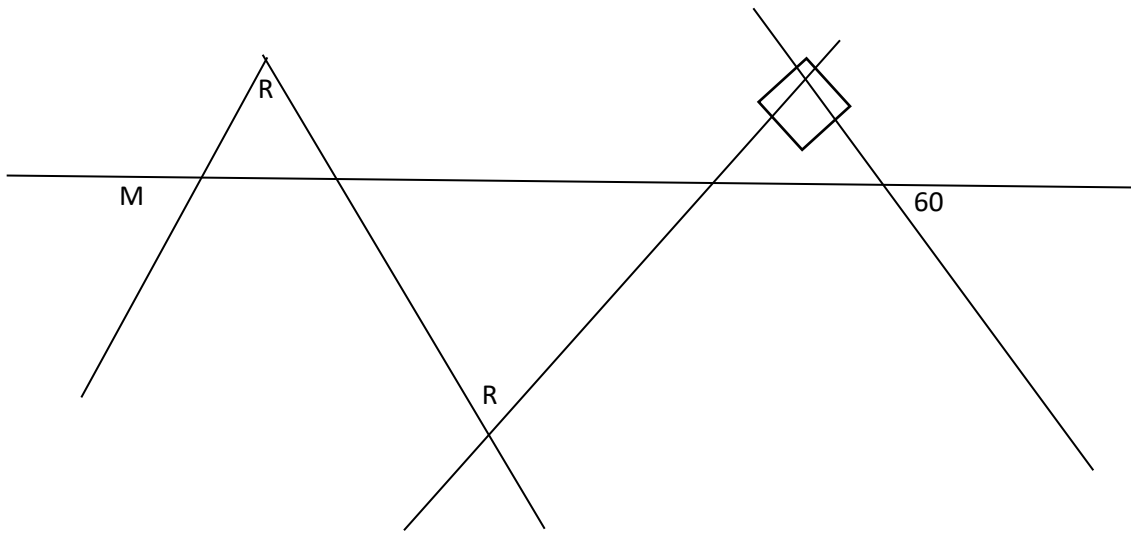


MNOP is a rectangle

Area of triangle PQN = 10

Area of rectangle MNOP =

Questions No. 7



$M =$

Survey Questions

Name:

OU ID:

1. How old are you? (In years)

2. How do you describe your gender?

- ☐ Female
- ☐ Male
- ☐ Non-binary/third gender
- ☐ Prefer not to say

3. What race/ethnicity best describes you?

- ☐ American Indian/Alaskan Native
- ☐ Asian/Pacific Islander
- ☐ Black/African American
- ☐ Hispanic
- ☐ White/Caucasian
- ☐ Multiple Ethnicity/ Other

4. What is your major at OU?

- ☐ AME
- ☐ CEES
- ☐ ISE

- If other, please write below:

5. What high school did you graduate from (name of school, city, state)?

6. How large was your high school graduating class?

- <50
- 50+
- 100+
- 200+
- 300+

7. What was the name of the final math course you took in high school?

- Algebra II
- Geometry
- Pre-Calculus/Trigonometry
- Statistics
- Calculus
- If other, please write below:

8. Have you ever taken a CAD or drafting course?

- ☐ Yes, before entering college
- ☐ Yes, while in college
- ☐ No

9. What drafting program did you learn? (leave blank if it was a hand-drafting course)

10. Have you ever taken an art course where you drew 3D objects with or without "perspective"?

- ☐ Yes, before entering college
- ☐ Yes, while in college
- ☐ No

11. Have you ever taken any "shop" classes or Industrial Tech. classes?

- ☐ Yes, before entering college
- ☐ Yes, while in college
- ☐ No