# AC 2012-3987: SPATIAL ABILITY IN HIGH SCHOOL STUDENTS

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# Spatial Ability in High School Geometry Students

## Abstract

Spatial ability is a skill necessary in a number of disciplines, particularly in engineering education, the focus of this research. This study reviewed literature regarding the development of spatial ability and considered possible implications not only for engineering education but also for mathematics education, with specific regard to geometry. The focus of this study was to observe the differences in spatial ability among high school students in PreAP Geometry and students in an Introduction to Engineering Design course. We hypothesized that the students who were enrolled in both courses would have better spatial ability skills than those students who are solely enrolled in the geometry course.

Of the 207 students enrolled in geometry at the test school, there was a smaller population (n=57) simultaneously enrolled in an engineering graphics course. No direct or special intervention was given to either group of students; however, the curriculum between the two classes differed greatly. Near the end of the academic year all students were administered the Purdue Visualization of Rotations test (ROT). Results showed that students enrolled in the engineering design class performed better than those students not enrolled in the course. Furthermore, the males outperformed the females when all students were considered. However, there was not a significant difference among the males, nor was there a difference between males and females within engineering. Further research is needed to understand these particular differences and to determine how geometry education plays a role in the development of spatial ability.

## 1. Introduction

Change is inevitable, and the world today is changing at a far quicker rate than ever before. Many of the jobs that existed 25 years ago are becoming obsolete due to numerous improvements and developments in technology. As secondary educators attempt to prepare students for the future, it is vital to understand that the future is unknown and ever changing. According to Jukes and McClain[1], "we must recognize that the current education system has been set up to prepare students perfectly for a world that no longer exists." As education in the United States is in the process of great transformation, educators and policy makers have the task of determining the components and skills that are essential in education and that are vital in the preparation of students for the future.

Science, Technology, Engineering, and Mathematics (STEM) Education is at the forefront of this change. Educators are striving to find better ways of not only imparting knowledge but also building communication skills, developing analytical skills, getting students to think and problem solve, and challenging students to be innovative. It is not a matter of whether the students have the knowledge to perform a task that has been modeled before them; rather, they must have the ability to take that knowledge and think about tasks in new ways to arrive at appropriate solutions, solutions which may not have previously existed. In order for students to be successful in this innovative way of learning, they must possess a number of vital

skills and abilities. One such ability that seems to be essential in STEM education is spatial reasoning ability.

This paper discusses the need for spatial ability education by examining the multiple approaches students use on spatial ability tasks and how this skill can be developed with time and intervention. Differences in curricula and the roles these differences potentially play in developing spatial ability are identified. Finally, this paper discusses the results and analysis of one study in which spatial ability was measured in a particular group of high school students to determine the role that engineering plays in developing this ability.

## 1.1 Spatial Ability Defined

Scholars have defined spatial ability in a number of ways over the years. Olkun divided spatial ability into two main categories: spatial relations and spatial visualization. According to Olkun, the spatial relations category is defined as "imagining the rotation of 2D and 3D objects as a whole body" whereas spatial visualization is defined as "imagining the rotations of objects and their parts in 3D space in a holistic as well piece by piece fashion."[2] McGee described spatial ability as one that requires "changing, rotating, bending, and reversing an object."[2] In addition, Thurstone divided spatial ability into three categories: "ability to recognize the identity of an object when it is seen from different sights, the ability to imagine the movement of internal displacement among the parts of a configuration, the ability to think about those spatial relations in which the body orientation of the observer is an essential part of the problem."[2] No matter the precise definition used, spatial ability as a whole encompasses one's ability to generate, recall, and manipulate 3D objects within one's mind.

Spatial ability is significant in a number of disciplines including, but not limited to, engineering, architecture, biomedical sciences, robotics, and geographical information systems. Due to this significance, educators are forced to ask: How does one develop such a skill? According to Piaget, spatial ability is developed through three stages. The first stage is topological spatial visualization where one can determine the distance between objects as well as an object's location in reference to other objects. The second stage is projective representation where one can visualize what an object will look like from various perspectives. In the third stage one can combine projective representation with the idea of measurement.[3] Although the development of spatial ability in education is often associated with engineering education, this is not the sole discipline in which this ability is utilized or developed. Geometry education contributes significantly to the development of spatial ability. As educators look for ways to develop spatial ability in engineering students, they should not overlook the geometry education of such students.

## 1.2 Spatial Ability in Geometry and Engineering Education

Geometry education can be defined as the study of size, shape and location of objects in reference to one another. It is generally in a high school geometry course that students find themselves intensely studying three-dimensional figures. According to the National Council of Teachers of Mathematics, high school geometry students are expected to "analyze properties and determine attributes of two- and three-dimensional objects; explore relationships…among

classes of two-and three-dimensional geometric objects, make and test conjectures about them, and solve problems involving them".[4] In addition, geometry students are expected to draw and construct 2D and 3D objects, visualize 3D objects from different perspectives, and use geometric ideas to solve problems in other disciplines such as art and architecture.[4] The Texas Essential Knowledge and Skills for Mathematics states that one objective of high school geometry is that of geometric thinking with spatial reasoning. It states "spatial reasoning plays a critical role in geometry; geometric figures provide powerful ways to represent mathematical situations and to express generalizations about space and spatial relationships (TEKch 111.34.2).[5] From these standards alone it is evident that one underlying focus of geometry education is the development of spatial ability.

It is this spatial ability that researchers have claimed has a direct effect on the success of engineering students. Sorby and Veurink claim that "spatial skills have been shown to be important to success in many technical fields and have been found to be particularly important to success in engineering graphics".[6] Studies have shown that at the collegiate level, students with better spatial ability do better in engineering graphics courses. Engineering graphics is a foundational course for most engineering disciplines. While engineering graphics courses at some universities are becoming less important as graduation requirements due to the perceived importance of other classes, spatial ability remains a necessary skill to possess. It has been shown that spatial ability is not a skill that a person either has or does not have. Spatial ability is a skill that can be developed, and even at a later age improved with intervention.[2,3,7-10] Therefore, it is worthwhile to consider various methods that might be successful in the development of spatial ability.

Although there is abundant research investigating spatial ability in engineering education as well as in mathematics education, there is little to no research investigating the spatial ability of high school students who are simultaneously enrolled in geometry and engineering. The purpose of this study was to look at precisely just that. The hypothesis for this research was that students who are enrolled in both high school PreAP Geometry and Introduction to Engineering Design would have better spatial ability skills than those students who are solely enrolled in PreAP Geometry.

## 2. Review of Literature

"Many of the well-publicized engineering failures in the recent past (including the Challenger explosion, the Hubble space telescope, the Tacoma Narrows Bridge, and the USS Vincennes Aegis system among others) occurred largely because of the elimination of visual, tactile, and sensory aspects from the engineering curriculum of today." This claim by Ferguson[10] certainly causes an educator to pause and consider the implications of the curriculum which they teach. As a result, this visual perception and spatial skill set of students must certainly be addressed. There is much evidence to support the need for spatial ability. Therefore a deeper look into the need for spatial ability, the development of spatial ability, how students approach spatial tasks, and how spatial ability is assessed is an important step in the process of determining what is essential in STEM education today. In addition, numerous approaches have found success in further developing the spatial skills of students and hold great implications for STEM education as it continues to evolve.

## 2.1 Need for Spatial Ability

A survey conducted by the American Society for Engineering Education stated there were two graphical communication outcomes that were most important in engineering graphics. The first was the ability to create models of 3-D solids on the computer, and the second was the ability to sketch engineering objects in freehand mode.[8] These skills become vital in the success of professionals in the engineering field and are directly linked to a person's spatial ability. Spatial ability is important in tasks such as "designing and documenting parts to be assembled, imagining the shape of cut hillsides for highway construction, laying out circuit designs, or finding optimal crystal configurations".[7] In addition, spatial ability has been linked to success in problem solving in engineering[11] as well as the ability to effectively learn and use computer aided design software.[10] In order to prepare students adequately for an engineering career path, educators must understand the development of skills such as spatial ability.

## 2.2 Spatial Ability Development

Although the main emphasis remains on spatial ability, it is important to note that spatial ability is rarely used in isolation[7] or developed solely through engineering instruction. The early years of one's life as well as geometry education serve as important factors in the spatial skill set that a student possesses. Sorby and Veurink found that a number of activities appear to assist in the development of spatial ability.[6] Playing with construction toys as a young child, participating in a sport that requires hand-eye coordination, and playing 3-D computer games are just a few. In addition, drafting and shop classes in middle/high school and well-developed mathematical skills all seem to play roles in the development of spatial ability.[6]

In addition to these activities, Velichova defines three levels at which spatial ability is developed through geometry education: (1) views of elementary solids and drawing simple plane figures; (2) calculation of geometric properties such as surface area and volume, with extension of these properties to the more complex ones involving calculus, coordinate geometry, and constructional problems with solids; and (3) use of upper level calculus, geometric modeling, and computers to aid in the constructing and visualizing of models. Educators involved with the instruction of geometry must fully understand the impact such education can have on students and potential future engineers.

Integrated within these three levels of learning, is geometry education as a whole. Baki states the objective of geometry education as the following: "the student should use geometry within the process of problem solving, understanding and explaining the physical world around them".[2] In order to achieve this level of reasoning, one requires a solid understanding of models. Velichova explains that models have been with civilization since the beginning of time and have served as a means of communication. Models hold great value as they are independent and understood by almost any level of literacy.[12] The ability to create models such as sketches and diagrams is directly related to spatial ability. In order to solve problems using models and graphical representations, a "relatively high abstraction level is required to comprehend the geometric construction rules needed to perform an in depth complex graphical representation of a real situation".[13] It is this high abstraction level with spatial ability that educators should aim to

develop within geometry education, and yet most research on spatial ability excludes geometry education and focuses solely on engineering education. However, it seems as though geometry education has the potential to be a building block for engineering education and thus provides the basis for this particular study.

## 2.3 Spatial Ability Approaches

In order to educate students to attain this high level of abstraction, one must first understand the multiple approaches students might follow when attacking a spatial task. The two primary processing strategies are the holistic and analytical approaches. Bodner and Guay define the holistic approach, or gestalt processing, to be "when an individual forms and transforms visual images as an organized whole."[14] In contrast, the analytical approach involves a systematic process where the whole part is broken down into individual pieces using a one-to-one relationship between the parts.[14] A third approach is the patterned-based approach where one breaks the problem down into simpler and separate elements that have been used previously.

Hsi describes these differences well in the familiar cube counting task (Figure 1). Students using a holistic approach on this task would visualize the object as a whole and rotate the object mentally to determine the number of cubes touching. Students using the analytical approach would count the cubes systematically from left to right and top to bottom. This approach does not require much visual rotation.[7] In addition, the students using the pattern-based approach would abstract "the problem into familiar elements such as single columns or planes of blocks" and reduce "the solution to cases previously solved."[7]



Cube Counting:
    Assume that:
        • all cubes are the same size and shape
        • there are only enough hidden cubes to support
          the visible cubes
        • cubes touch if any parts touch, even an edge or a
          corner
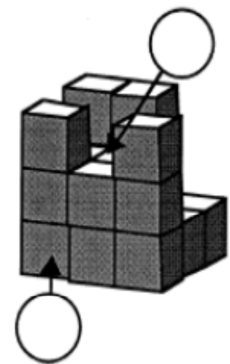For each marked cube on the right, determine how many cubes touch it.

**Figure 1.** Cube counting exercise.[7]

Although gender differences are not the primary focus of this research, it is noteworthy to mention that males and females tend to approach spatial tasks differently. According to Linn and Petersen, males tend to favor the holistic approach whereas females tend to be more analytical.[10] This fact might explain why males generally outperform females on spatial tasks, possibly due to the speed required on some spatial ability assessments. In addition, Cooper found that those favoring a holistic approach can utilize an analytical approach when the task requires an analytical method to obtain a solution.[7] However, research seems to focus on spatial ability as a whole rather than homing in on the means of approaching such tasks.

## 2.4 Improving Spatial Ability

A number of studies have investigated the development of spatial ability through specific means of intervention. One particular study focused on a small test group of 16 middle school students who were enrolled in an Integrated Technology course at the time. The students worked with a combination of workbook exercises with coinciding computer tutorials. Results showed the students preferred working with both the workbook and computer and the time spent was effective in improving the spatial skills of those students.[10] However, because of the relatively small sample size, it is difficult to know if similar results would follow with a larger population. In addition to the middle school students, the same material was used to examine a group of high school students. With this group of students, nine modules were integrated into their regular geometry course at the beginning of the year. Again, the results showed improvement in spatial ability. Interestingly enough, this study showed that the gender gap may have actually increased rather than decreased.[10] However, this finding is not consistent with other research, and provides some thought for future study.

Sorby's research does not stop at the middle and high school levels. In 1993, Sorby and Baartmans developed a ten week pre-graphics college course with an accompanying textbook. The text was written to follow the sequence needed to develop 3-D spatial skills.[3] In the beginning of the course, students were introduced to the need for spatial visualization skills and primarily focused on isometric and orthographic sketching. The curriculum built upon this skill while adding various application problems, discussing engineering drawings, and focusing on pattern development. Approximately half way through the curriculum, students were exposed to wireframe geometry as they concentrated on two and three coordinate drawings. Transformations became integral at this point as students used translations, dilations, rotations, and reflections to view objects as they are rotated about axes and investigated cross-sections.[3] Data shows statistically significant gains were made by the students enrolled in the specialized course. Not only did the students score better on the spatial ability exams, but it was also shown that over time, the students who had taken the course had higher grades in their graphics courses and higher retention rates in engineering.[3]

Although other studies and targeted training at the collegiate level may not have been as extensive as the research of Sorby and Baartnams, they still seem to shed light on other targeted methods of improving spatial ability within students. In one such study, a group of freshman mechanical engineering students who were enrolled in a CAD course were given the Purdue Spatial Visualization Test, and based on their scores they were divided into three groups: low, intermediate, and high. The low group was given the opportunity to attend targeted training. This training took place over four weeks with approximately four hours of training each week using the Physical Model Rotator and the Alternate View Screen, both CAD type applications.[9]

The results certainly favor the targeted training. Overall, spatial ability scores for the group increased, and they improved on every object and rotation type question. The scores were significantly better than those in the low group who chose not to participate in the targeted training. In addition, the low group that received the targeted training essentially caught up to the intermediate group by the end of the semester. This is yet another example that supports the idea that targeted training, particularly that involving CAD software, can make a difference in

the spatial ability in students.[9] This also reveals there may be multiple software programs that can aid in developing spatial ability.

Another CAD software program that has been used in targeted training is Google SketchUp. In a study with a group of civil engineering students, this software was used for a three week targeted training which required 12 hours of work from students. The training was broken into three sessions, each containing eight hours in the classroom followed by four hours of homework.[8] Similarly with other curricula, the results of this study showed that using Google SketchUp had a definite and positive impact on the spatial ability of the students.[8]

Cabri 3D is yet another program that can be used in developing spatial abilities. This program was used on a group of mathematics teachers. For a time period of eight weeks, the teachers completed various activities using Cabri 3D for approximately one and a half hours each week. The data collected provided evidence that the training with Cabri 3D did in fact contribute to the development of the spatial skills.[2]

Any educator knows that not only is the method important in developing spatial skills of students, but also the time commitment when it comes to incorporating the selected strategies into the curriculum. Therefore, it is worthy to briefly mention yet one more study where the training of students only lasted three hours. In this study, a group of first-year engineering graphics students was given a pre-assessment on spatial ability. As a result, at-risk students were invited to attend a three hour Saturday morning tutorial session, but it was also open to any other student who wanted to attend. The session combined computer activities in Block-Stacking and Display Object with paper based exercises. Prior to the session, males outperformed females on the engineering items, orthographic drawing and isometric views. However, no gap appeared between genders on traditional items such as cube counting, object rotations, and pattern matching prior to training. According to the research, gender differences seemed to disappear after training.[7] Although this may seem like a quick way to get the desired results, it should be noted that the post-assessment was not completed until the end of the semester. Therefore, it would be interesting to consider how much of the improvement was based on the intervention versus the additional time spent in the classroom over the semester developing such skills, where perhaps some of the students would have made similar gains with just the exposure to the engineering graphics class.

Based on these studies, it is evident spatial ability is a skill which can be improved upon given the right type of learning environment and instruction. It has been shown that this improvement can take place over the course of several weeks or simply over a few short hours. Therefore, educators are left with the decision of how to implement strategies and curriculum which will be most valuable for students and in the end improve spatial ability skills as a whole. Despite the differences in the research, there seems to be a common thread among most, if not all, of the research for improving spatial ability. At some level two main components seem to be prevalent: sketching and 3-D models.

## 3. Methods

This study was a post-test only design where the students were assessed once at the end of a particular topic of study involving spatial ability. The study received approval from The University of Texas at Austin Institutional Review Board and Lake Travis (TX) Independent School District, where the study was conducted. The students did not receive any special instruction regarding the topic. The only instruction given was that which was consistent with the given curriculum. All students enrolled in PreAP Geometry were given the Purdue Visualization of Rotations Test (ROT) near the end of the school year. From the data gained, the goal was to evaluate the spatial ability of those students who were solely enrolled in PreAP Geometry versus those who were simultaneously enrolled in Introduction to Engineering Design. In addition to this data, gender differences with respect to spatial ability were analyzed.

### 3.1 Curriculum

The curriculum was the primary difference among the two groups of students. All students were exposed to the PreAP Geometry curriculum, while a subset of the sample population was also exposed to the Introduction to Engineering Design curriculum over the course of the school year. Both curricula spent some time dealing with the development of spatial ability, but they did so in different ways and to varying depths. For all students involved in this study, the PreAP Geometry curriculum was standard. Although there were four different instructors for the PreAP Geometry students, the curriculum as a whole was consistent throughout all classes. The instructors worked closely together to follow the same scope and sequence and develop lesson plans. Although the delivery may have varied slightly, the same types of notes, activities, handouts, assignments, and exams were used.

The geometry curriculum was based on the Texas Essential of Knowledge and Skills[5] (TEKS) and followed the scope and sequence set forth by the school district. The primary resource for practice problems for the students was found in the Holt Geometry textbook[15] The geometry scope and sequence had 12 total units with one unit specifically focused on spatial ability and its application. The unit was seven class days in length, six of which were instruction days. The unit began by introducing students to 3D figures using nets (developments) and cross sections. Students were expected to recognize nets of various 3D solids and identify the cross sections of 3D solids when cut parallel or perpendicular to the base of the solid. The curriculum then exposed the students to isometric drawings and orthographic views. Students were expected to take a 3D or isometric view of a basic solid and sketch the six different orthographic views. From there, the curriculum expanded into surface area and volume exercises with some exercises integrating the application of surface area and volume to real-world examples. Even though the unit included six instructional days, only one day was devoted to nets (developments), cross sections, isometric views, and orthographic views. The remainder of the unit was spent on surface area and volume and the application of such concepts. It is also worth noting that although research emphasizes sketching and 3D models as foundational to spatial ability development, minimal time was spent on these topics in the PreAP Geometry classroom.

In contrast, the Introduction to Engineering Design (IED) curriculum incorporated ample practice on sketching and 3D models. The course followed the curriculum set forth by Project

Lead the Way[©] (PLTW).  This is a project-based curriculum that primarily follows the parts-to-whole approach regarding spatial ability development.  Students who were enrolled in IED not only received minimal exposure to spatial ability through their PreAP Geometry class, but they also spent much of the year using their spatial ability skill set throughout their engineering class. With regard to spatial ability, the IED class spent the beginning of the year learning about isometric and orthographic views.  Beyond simple recognition of these items, the students spent about nine weeks sketching isometric and orthographic views of 3D solids throughout their coursework.  The remainder of the year covered various concepts, but the emphasis on sketching remained.  For example, students spent a unit on reverse engineering where they measured tangible objects and parts while providing annotated sketches of these items.  No project takes place without the use of sketching.

In addition to sketching, students spent a great deal of time constructing and manipulating 3D objects on the computer.  As students began constructing 3D models on the computer they used Autodesk Inventor[©], and they continued to build models in this software throughout the entire course (Figure 2).  At times this meant students took existing isometric and orthographic drawings and created 3D models of the parts.  Once created, the students were able to assemble and manipulate the parts to create full working models on the computer.  At other times the projects required students to develop their own parts that would assemble into a larger unit. These parts were always sketched first and then modeled.  By the end of the curriculum, students were expected not only to sketch 2D views and create 3D solids on the computer but also be able to transfer back and forth between 2D and 3D representations.  The large amount of time devoted to sketching and 3D models served as the basis for the hypothesis that students who were also enrolled in Introduction to Engineering Design would outperform those who were not enrolled in the course when it came to tasks requiring spatial ability.
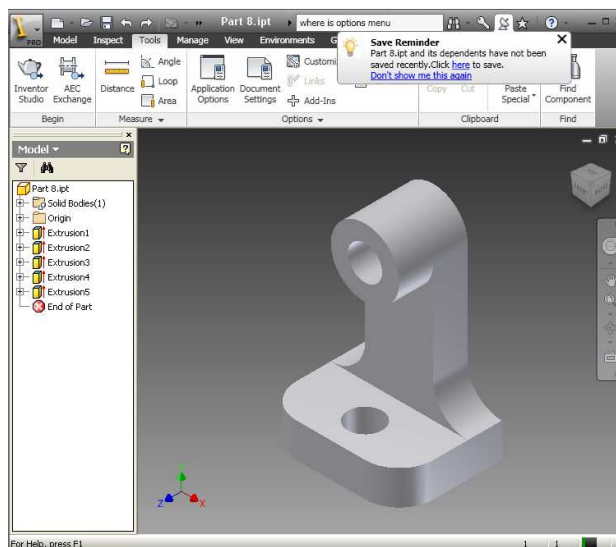


**Figure 2:**  Sample screen from Autodesk Inventor software.

Although an entire unit was devoted to spatial ability in the PreAP Geometry curriculum, it was evident that very little class time was actually devoted to the development of necessary skills for spatial ability.  However, the curriculum still expects students to utilize these skills in a number of different applications through surface area and volume.  On the other hand, the IED

curriculum spent a great deal of time on these skills even though the development of spatial ability was not generally the primary learning objective. However, the combination of sketching and the usage of 3D modeling software suggests that the development of spatial ability would certainly be a byproduct of the classroom curriculum.

## 3.2 Sample

This study was conducted at large high school of 2,077 students with 73.5% being White and 17.4% Hispanic. Of these students 26.9% were considered at-risk, and 12.4% were considered economically disadvantaged. In addition, the campus had a 94% passing rate on the mathematics state assessment (TAKS) with 50% commended. Science was similar with a 98% passing rate with 48% commended The study was conducted near the end of the 2010-2011 academic year. All students involved in this study were enrolled in PreAP Geometry (n = 207). The two groups of interest were those students enrolled solely in PreAp Geometry (n=150) and those simultaneously enrolled in Introduction to Engineering Design (n=57). PreAP Geometry is optional for students; they can opt to take regular geometry to gain credit for geometry. The PreAP Geometry classes were selected over the regular classes due to a larger sample population of engineering students existing in PreAP Geometry than in regular geometry. In addition, the geometry curriculum provided the most content with regards to spatial ability tasks. The PreAP Geometry class moves at a quicker rate and covers topics to a greater depth than a regular Geometry class. The sample consisted of approximately 48% females and 52% males. There were nine different PreAP classes involving three different teachers and one student teacher. The students who were also enrolled in Introduction to Engineering Design were dispersed throughout six different sections involving two different teachers. This class is also an optional class, and it counts as an elective towards graduation. However, in both instances it is assumed the level of instruction was as consistent as possible throughout all classes, and no individual class received any special treatment or instruction.

## 3.3 Assessment

The instrument used to assess the students was the Purdue Visualization of Rotations Test (ROT) which is a shortened version of the Purdue Spatial Visualization Test of Rotations (PSVT:R) which originally had 30 questions.[3] As noted earlier, it was administered to all PreAP Geometry classes at the conclusion of a unit specifically emphasizing spatial ability. The ROT consists of 20 multiple choice questions, each with five answer choices. A sample question is shown in Figure 3. The exam shows the student an object and a view of the same object after being rotated in a given direction. Then a second object is presented and the student is asked to identify the view corresponding to the second object if it were rotated in the same manner as the first. The instrument provides students with two sample questions prior to the twenty questions. In all classes, the teacher read through the directions on the test and the two sample questions with the students.
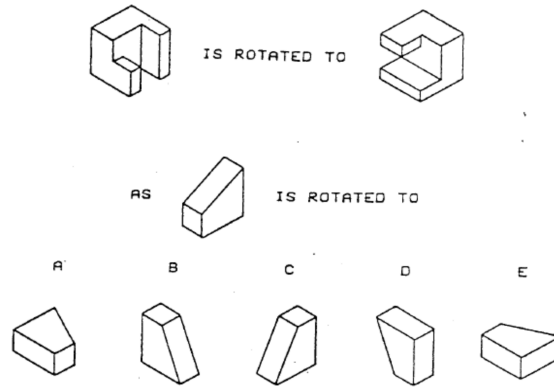
**Figure 3.** Sample question from ROT assessment.[14]

The instrument is designed to be administered in ten minutes; however, a time modification was made. The high school students were given 18 minutes to complete the assessment. Almost all prior studies using this assessment involved college students. The one study that used middle school students modified the questions to have fewer answer choices. Rather than having fewer answer choices, it was decided to extend the time limit to 18 minutes, under the assumption that was a sufficient amount of time for all students to complete the test. Although the level of difficulty on the questions seems to increase as the test progresses, each question was weighted equally. Therefore, the minimum achievement score possible was zero, and the maximum achievement score possible was 20.

All exams and answer sheets were collected and given to the researcher. The items were then graded and compiled. The data was graphed to approximate normality between each group being compared; however, not all groups had a normal distribution. An independent two-sample t-test was performed using StatCrunch[©].[16] Since not all groups had a normal distribution, additional analyses were run using SPSS to obtain Shapiro-Wilk's test of normality, Levene's test for equality of variances, and a t-test for equality of means in order to confirm an independent two-sample t-test was feasible.

## 4. Results and Data Analysis

For the statistical analysis an independent samples t-test was used between the two groups, using the null hypothesis ($H_0$) that spatial visualization abilities did not vary between the groups. Results showed that the two groups did differ in spatial visualizations abilities, $t(104.00) = -2.20$, $p = 0.02$, Cohen's $d = 0.339$, with those students in engineering scoring higher on spatial abilities (M = 15.25, SD = 3.34) than the students solely enrolled in geometry (M= 14.09, SD = 3.44). This means that assuming the null hypothesis is true, there is less than a two percent chance of obtaining these results. Therefore, the null hypothesis is rejected and we can conclude that the engineering course had a positive and measurable impact on the students.

Although the primary focus of this study was to look at the differences in spatial ability between the students in Introduction to Engineering Design and PreAP Geometry, differences between genders were also analyzed. With all analyses an independent samples t-test was used between the two groups in question, again using the null hypothesis ($H_0$) stating that spatial visualization abilities did not vary between groups, males (n = 108) and females (n = 99).

Results showed that males and females also differed in spatial visualization abilities, $t(205) = -2.95$, $p = 0.002$, Cohen's $d = 0.40$, with males scoring higher (M = 15.07, SD = 3.17) than females (M = 13.69, SD = 15.07). Therefore, the data indicates that males were significantly higher in spatial ability than females throughout the entire sample population.

Further investigation provides more insight into this difference between genders. When the data were analyzed between males (n = 60) and females (n= 90) for only those students in geometry, the results showed that males were certainly better than females $t(139.39) = -2.8831$, $p = 0.002$, Cohen's $d = 0.47$, with males scoring higher (M = 15.03, SD =3.04) than females (M = 13.467, SD =3.570). On the contrary, when the data were analyzed between genders for only those students enrolled in engineering, it was assumed the males would still outperform females. However, the results showed no significant difference between males (n = 49) and females (n = 9) enrolled in engineering such that $t(11.273) = 0.630$, $p = 0.541$, Cohen's $d = 0.22$, with females enrolled in engineering (M = 15.88889, SD = 1.111) comparable to males enrolled in engineering (M = 15.125, SD = 3.362).

Due to this difference a further analysis was completed with the males and females, respectively, with regard to enrollment in engineering. There were not significant differences in spatial abilities between those males that were enrolled in engineering (n = 48) in comparison to those that were not (n = 60). Results showed $t(106) = -0.15$, $p = 0.4411$, Cohen's $d = 0.029$, with the males enrolled in engineering scoring comparable (M = 15.13, SD = 3.36) to the males only enrolled in geometry (M = 15.03, SD = 3.03).

In contrast it appears there was a significant difference among females. Again, and independent samples t-test was used between females in engineering (n = 9) and females not enrolled in engineering (n = 90). Results showed $t(9.9) = -2.06$, $p = 0.03$, Cohen's $d = 0.70$, with the females enrolled in Engineering scoring higher (M = 15.89, SD = 3.33) than the females exclusively enrolled in PreAP Geometry (M = 13.47, SD = 3.57).

When examining the results, it appears the hypothesis is moderately supported. The engineering students did perform better than the students only in geometry. In addition, the males outperformed the females. However, this was only the case when it came to students not enrolled in engineering. A further look revealed there was not a significant difference among the males in engineering versus the males only in geometry, but there was a difference between the two groups of females. Therefore, it seems the females enrolled in engineering are the driving force for this difference among the students. By examining the effect size of each comparison group, more insight can be gained. According to Cohen a small, medium, and large effect size would be calculated to be 0.2, 0.5, and 0.8, respectively.[17]Although the data was statistically significant for the engineering students versus the geometry students, the effect size was relatively small (d = 0.33). Therefore, it is unknown at this time as to what the level of impact the curricula had on the students. Similar results were found when looking at gender differences among the entire sample as well as gender differences between those only enrolled in geometry. However, these results further support gender differences in existing research.[3, 6-8] In contrast, the effect size for the females in engineering versus those solely in geometry was relatively high (d = 0.7). Despite the small sample size, the effect size seems to further support the idea that the

females in engineering made a significant difference in the results of this study and holds some practical significance as well.

There are certain limitations with this study that should be considered when interpreting the results. The sample population was chosen due to their enrollment in PreAP Geometry. Optional enrollment in this higher level course may eliminate a number of extraneous variables. However no data was analyzed regarding variables such as mathematical ability, motivation, and socioeconomic status. Although these factors may have provided some bias, they most likely did not compromise the results found between the males and females. These results only further support previous findings that males tend to outperform females on spatial ability tasks.[3,6-8] In addition, the results also support research where gender differences disappeared after targeted training.[7]

Additionally, the means by which the assessment was proctored may hold some significance. According to Bodner and Guay, the best measures of spatial ability are those tests that maximize the gestalt processing and minimize the analytical processing.[14] However, the time limit on this test administration was extended to allow most students, if not all, time to complete the 20 questions. Since Linn and Petersen reasoned that females are more analytical and males tend to be more holistic[10], it could be assumed the gender difference might disappear in this study. Interestingly this factor did not make a difference with those students only enrolled in geometry; the difference still remained despite the additional time. However, looking at the students only in engineering, this time limit may have aided the females. Further research might allow one to determine if females and males in engineering would still have the same result if the ten minute time limit had been in place. Possibly the females in engineering performed better due to the time extension, or perhaps it was due to the exposure to the class content or a number of other unknown variables.

With regard to the males, the extension of time may certainly have had some implications. With no significant difference between the two groups of males, one could conclude the class had no effect on the engineering students. However, possibly a difference did exist, but the extra time allowed the males not enrolled in engineering enough time to process through additional problems rather than reducing it to a test of speed. Or perhaps, by the time male students are approximately freshmen in high school they have developed their spatial ability skill set for the most part, which means their spatial ability development throughout childhood plays a role.

The most significant limitation on this study is the absence of a pre-test. Since the students were not assessed on their abilities at the beginning of the year, there is no baseline to which we can compare results. Although a pre-test may not have aided in the understanding behind the males outperforming females, it would most likely shed light on the other comparisons. Even though the engineering students performed better than the geometry students, it would be worthwhile to know if those students had better spatial ability skills entering the year. Furthermore, baseline data would allow for many more insights when looking at the results of males and females respectively. With no significant difference between the males, it may be possible to conclude that the engineering class did not help these students develop better spatial skills, but without a standard of comparison that idea cannot be ruled out.

In addition, a pre-test would allow a further look into the nine females enrolled in engineering. Although the sample size was small, the results showed a significant difference between females in engineering and those only in geometry. It could be concluded that the class certainly had a positive effect on the spatial ability based on the findings. Without a pre-test we do not know if the results are from a gained ability or an existing ability these particular females possessed.

Based on the results of the data and an examination of the study, a number of recommendations can be made for further analysis and study. Initially all potential bias should be removed to the extent possible. Further data collection on the samples could potentially eliminate any factors such as mathematical ability and socioeconomic status which could skew results. Additionally, it is recommended to revert back to the original time limit of ten minutes. This would most likely result in a closer to normal distribution of the scores. This might also allow us to see if there is potentially a difference within males. Future research should utilize a pre-test and post-test, allowing for far more conclusions to be reached. It is also recommended to perform further analysis regarding the effect size and whether the effect size represents a practical significance between groups of students. As Coe cautions, effect size can be somewhat limited since the average is many times based on "widely differing components" and therefore, the best estimate of effect size is when the study has been repeated.[18] With that knowledge, it is recommended to further explore the effect size of the sample populations and determine the relevance the effect size has, if any, on the practical significance of these results. Despite the limitations of this study, the results still allow us to consider the geometry education of students with regard to spatial ability. Findings like this further support the idea that experience with some form of CAD software aids in the development of spatial ability, which is consistent with prior research.[2,3,7,9,11] Therefore, geometry educators need to consider how such software can be integrated into the curriculum in a meaningful way.

## 5. Conclusions

As educators in STEM education attempt to improve upon the existing curriculum, they need to consider the significance that spatial ability holds. According to Alias, "enhancing spatial visualization skills in engineering students is important as this ability has been associated with success in problem solving in engineering."[11] It is because of this importance that educators need to fully understand what spatial ability is and the different approaches students take when solving spatial ability tasks. Once this is understood, curriculum can begin to be evaluated and modified in order to improve the spatial ability of students. As noted in the literature, this can be accomplished in a number of different ways, and it is up to STEM educators to determine what this change will look like and which approach will meet the students' needs and prepare them for the unknown challenges of the future.

As noted earlier, geometry education holds great significance regarding the development of spatial ability in students and thus improving problem solving skills. Improving upon these skills in a geometry classroom will not only help those students pursuing career paths in engineering, but can also help students in many other STEM related career paths. In light of this research, it is evident that a skill such as spatial ability can be improved and developed within students.[2,3,7-10] Therefore, geometry educators need to ask how to practically implement

strategies to improve such a skill in our students. This alone provides a foundation on which we can build and make recommendations.

At this point in this research, it is recommended that geometry teachers start with themselves. They first need to become educated on the importance of spatial ability within students, so they can see what a vast population of students is in need of this skill. When the geometry teacher can see beyond his/her own classroom and place this vital skill in a much larger context, he/she is able to begin to look for ways to develop this skill. Within the classroom, it is recommended that geometry teachers start by requiring their students to do more sketching, particularly 3D sketching in free-hand mode. Geometry provides a great context for students to be sketching on a continual basis, but can many times seem like an insignificant skill compared to others necessary for student comprehension. One potential flaw in geometry curricula is that students can be academically successful in geometry and understand and apply the concepts without being able to sketch and conceptually understand the 3D context. Therefore, students walk away from the geometry classroom with tools and knowledge; however they have not improved or developed their spatial ability along the way.

In addition to sketching, teachers should look to software programs that can enhance their instruction and aid in the development of spatial ability if implemented correctly. As noted in the literature, the best intervention strategies included both sketching in free-hand mode and the use of 3D software programs. Geometry teachers need to first determine which software programs would best suit the needs of their students and then integrate them into geometry curricula. Teachers can also explore novel ways of getting students to think in the 3D manner, such as ways to visualize rotations without software. One such example could be the use of a Rubik's Cube[TM]. Teachers can use the Rubik's Cube[TM] to further push the limits of students in regards to 3D objects and visual rotations by providing them with a tangible object to explore. This would not only allow teachers to explore algorithms with their students, but also allow for students to explore a three-dimensional object where they are continually being asked to rotate various faces while taking into account the object as a whole.

This study not only reviewed literature regarding the significance and development of spatial ability, but it specifically examined spatial ability within high school geometry students. The results of this study revealed differences between PreAP Geometry students and students in Introduction to Engineering Design regarding spatial ability. In addition, the results showed there were definite gender differences in spatial ability with males outperforming females. However, this only seemed to be the case when the females not enrolled in engineering were taken into account. The females enrolled in engineering were comparable to the males, thus making one consider the impact the engineering design curriculum had on the students, females in particular. Further research is needed in this area to investigate the practical significance of the statistical findings and to further explore developing spatial ability as a means to improve problem solving and the avenues in which to pursue this. However, this study demonstrates that spatial ability differences are present at the high school level, thus supporting the need for spatial ability development to be an integral part of geometry education. It is here that students can potentially develop the high abstraction level required for spatial ability tasks. The geometry classroom is an ideal place in STEM education to provide a foundation and assist other disciplines as they utilize the necessary skills of spatial ability.

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