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Spatial Ability in High School Geometry Students

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Spatial Ability in High School Geometry Students

by

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Report

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Dedication

This work is dedicated to my family.

Without their love and support this would not have been possible.

Acknowledgements

I would like to thank Dr. Richard Crawford for his continual support and guidance throughout this process. In addition, I would like to thank the UTeach faculty who made this program possible and my fellow UTeach classmates for making this program such an enjoyable and enriching experience.

Abstract

Spatial Ability in High School Geometry Students

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The purpose of this study was to observe the differences in high school PreAP Geometry students in regards to spatial ability. The hypothesis states that students who are enrolled in both high school PreAP Geometry and Introduction to Engineering Design have better spatial ability skills than those students who are solely enrolled in PreAP Geometry. 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 at the high school. No direct or special intervention was given to either group of students. 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 enrolled in engineering. Further research is

needed to understand these differences and how geometry education plays a role in the development of spatial ability skills.

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Chapter 1: Introduction

Problem Statement:

Change. 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. The educational system is left with the choice to either keep up or be left in the dust. 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 (2010/2011), "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 law makers have the task of determining what components and skills are essential in education and what is vital in the preparation of students for the future that lies ahead.

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, building 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 but rather the ability to take that knowledge and think about a task in a new way to arrive at an appropriate solution, a solution which may not have 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 that of spatial ability.

Spatial Ability Definition

Scholars have defined spatial ability in a number of ways over the years. Olkun (as cited in Guven, 2008) divided spatial ability into two main categories: spatial relations and spatial visualization. According to Olkun, spatial relations is defined as "imagining the rotation of 2D and 3D objects as a whole body" whereas spatial visualization was defined as "imagining the rotations of objects and their parts in 3D space in a holistic as well piece by piece fashion.". McGee described spatial ability as one that requires "changing, rotating, bending, and reversing an object" (as cited in Guven, 2008). 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" (as cited in Guven, 2008). 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 (Yue, 2006). Due to this significance, educators are forced to ask: How does one develop such skills? According to Piaget, spatial ability is developed through three stages. In the first stage is topological spatial visualization where one is able to tell the distance between objects as well as an object's location in reference to other objects. The second stage is projective representation where one is able to visualize what an object will look like from various perspectives, and the third stage is where one is able to combine projective representation with the idea of measurement (as cited in Sorby and Baartmans, 2000). Although the development of spatial ability in education is many times referenced with engineering education, this is not the sole discipline in which this ability is utilized or developed. Geometry education holds great significance when it comes 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.

Spatial Ability in Geometry and Engineering Education

Geometry education can be defined as the study of size and shape in addition to the location of objects in reference to one another. It is generally in a high school geometry course where students find themselves intensely studying three-dimensional objects. 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" (NCTM, 2000). 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 (NCTM, 2000). 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). 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” (Sorby & Veurink, 2010). 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. As engineering graphics courses at some universities are becoming of less importance in the graduation requirements due to the need for 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 (Akasah & Alias, 2010; Guven et al., 2008; Hsi, Linn & Bell, 1997; Martin-Dorta, Saorin & Contero, 2008; Onyancha, Derov & Kinsey, 2009; Sorby et al., 2000). Therefore, it is worthwhile to consider various methods that might be successful in the development of spatial ability.

Purpose Statement

Although there is a body of research investigating spatial ability in engineering education as well as mathematics education, there is little research looking at high school students. Tran and Mitchell (2010) did examine math and science achievement scores of those students enrolled in engineering at the high school level; however, there is little research looking specifically at 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 have better spatial ability skills than those students who are solely enrolled in PreAP Geometry.

The hypothesis was tested by assessing a group of students on their spatial ability near the end of both of these courses.

Organization of Report

Chapter 2 of this report examines current research in the area of spatial ability. It discusses findings of peer-reviewed literature and closely examines spatial ability and its importance in education. The methodology for the assessment is discussed in Chapter 3 including the two curricula used and the assessment tool. Chapter 4 provides the results of the assessment, analysis of the results, discussion of the findings, and the implications for education at the secondary level. Chapter 5 provides a summary of the study with the major findings and reasoning for future research in the area of spatial ability.

Chapter 2: Review of Literature

Need for Spatial Ability:

"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." Such a claim stated by Ferguson (as cited in Sorby, 2009) certainly causes an educator to pause and consider the implications of the curriculum that 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 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 these spatial skills of students and hold great implications for STEM education as it continues to evolve (Akasah et al., 2010; Casakin & Kreitler, 2009; Guven et al., 2008; Hsi et al., 1997; Martin-Dorta et al., 2008; Onyancha et al., 2009; Sorby et al., 2000).

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 is the ability to create models of 3-D solids on the computer, and the second is the ability to sketch engineering objects in freehand mode

(Martin-Dorta et al., 2008). These skills become vital in the success of professionals in the engineering field and are directly linked to a person's spatial ability. Although there are many career paths that utilize spatial ability, much of the focus remains in engineering. 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" (His et al., 1997). In addition, spatial ability has been linked to success in problem solving in engineering (Akasah et al., 2010) as well as the ability to effectively learn and use computer aided design software (Sorby, 2009). In order to prepare students adequately for an engineering career path, educators must understand the development of skills such as spatial ability.

Spatial Ability Development

Although the main emphasis remains on spatial ability, it is important to note that spatial ability is rarely used in isolation (Hsi, et al., 1997) 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. Research by Sorby and Veurink (2010) found a number of activities appear to assist in the development of spatial ability. 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. They found that specific 3-D games such as 3-D Tetris, 3-D Blokus, and computer/video games that include action and adventure or require a person to navigate through a 3-D environment contribute as well. In addition, drafting and shop classes in middle/high school and well-developed mathematical skills all seem to play a role in the development of spatial ability (Sorby & Veurink, 2010). Based on this information it seems justified that those involved with mathematics education, specifically geometry, would spend some time considering how mathematics education can specifically aid in the development of spatial ability.

In addition to the activities noted, Velichova (2002) defines three levels at which spatial ability is developed through geometry education. The first level includes views of elementary solids and drawing simple plane figures. The second level builds upon the first and looks at calculating geometric properties such as surface area and volume. It continues to extend these properties to the more complex involving calculus, coordinate geometry, and constructional problems with solids. The third level is the advanced level where upper level calculus is required, geometric modeling is used, and computers aid in the constructing and visualizing of models (Velichova, 2002). Based on these three levels of spatial ability development, it is essential that those involved with the instruction of geometry fully understand the impact such education can have on students and potential future engineers. Although the research does not focus on the curriculum from a pedagogy viewpoint, the skill and understanding of the teacher on this topic should not be overlooked as it is the teacher who will facilitate and foster this development within the students.

Integrated within these three levels of learning, is geometry education as a whole. Baki states the objective of geometry education: "the student should use geometry within the process of problem solving, understanding and explaining the physical world around them" (as cited in Guven, 2008). 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 (Velichova, 2002). 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" (Cobos-Moyano, Martin-Blas, & Onate-Gomez, 2009). It is this high abstraction level with spatial ability that educators should aim to develop within geometry education, and yet most research on this topic of spatial ability excludes geometry education and solely focuses 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.

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 (1997) define the holistic approach, or gestalt processing, to be "when an individual forms and transforms visual images as an organized whole." 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 (Bodner et al., 1997). 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 (Hsi et al., 1997). 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” (Hsi et al., 1997).

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 with different strategies. According to Linn and Petersen (as cited in Sorby, 2009), males tend to favor the holistic approach whereas females tend to be more analytical. This fact alone might hold some significance as to why males generally outperform females on spatial tasks, possibly due to the speed required on some of the 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. (as cited in Hsi, 1997) However, research seems to focus on spatial ability as a whole rather than focusing on the means of approaching such tasks.

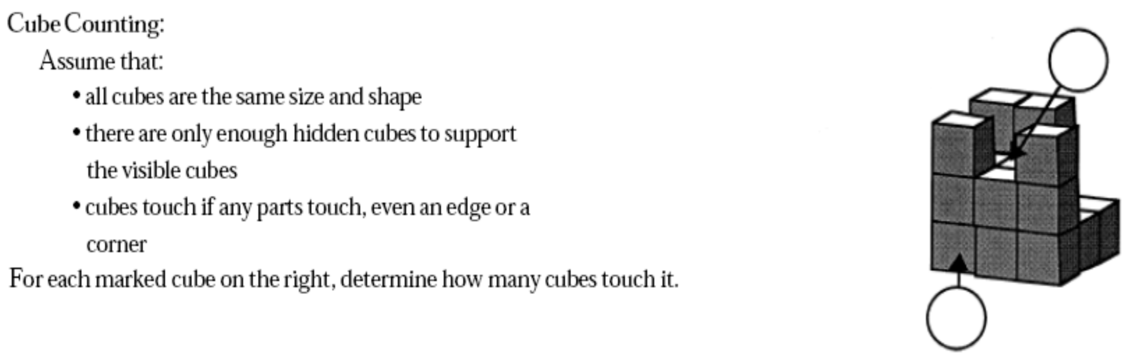

Figure 1. Cube counting exercise. (Hsi et al., 1997)

Spatial Ability Assessments

There are numerous assessments available for testing spatial ability, and different assessments measure different aspects of spatial ability. Traditional assessments have focused on testing for mental rotations and spatial visualization. These have included the cube counting, paper folding, and object rotation assessments. More engineering specific assessments have included items such as constructing orthographic projections and isometric views, reading blueprints, and drawing hidden views (Hsi et al., 1997). There are four commonly used assessments as cited in Sorby and Baartmans (2000): 1) MRT; Mental Rotation Test (Figure 2), 2) MCT; Mental Cutting Test (Figure 3), 3) DAT:SR Differential Aptitude Test: Space Relations (Figure 4), and 4) PSVT:R; Purdue Spatial Visualization Test for Rotations (Figure 5). According to Bodner and Guay (1997), tests that maximize the holistic processing while minimizing the analytical are said to be the best measures of spatial ability.

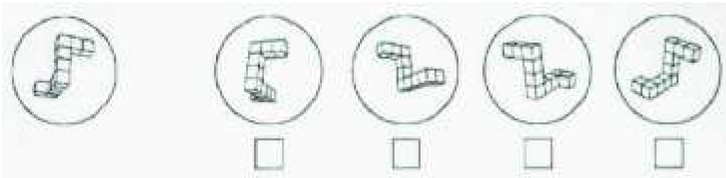

Figure 2. Sample problem from the MRT. (Martin-Dorta et.al, 2008)

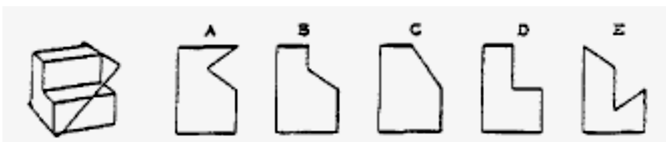

Figure 3. Sample problem from the MCT. (Sorby et.al, 2000)

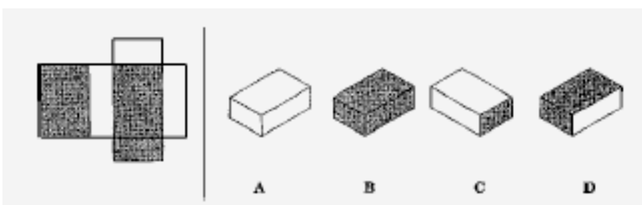

Figure 4. Sample problem from the DAT:SR. (Sorby et.al, 2000)

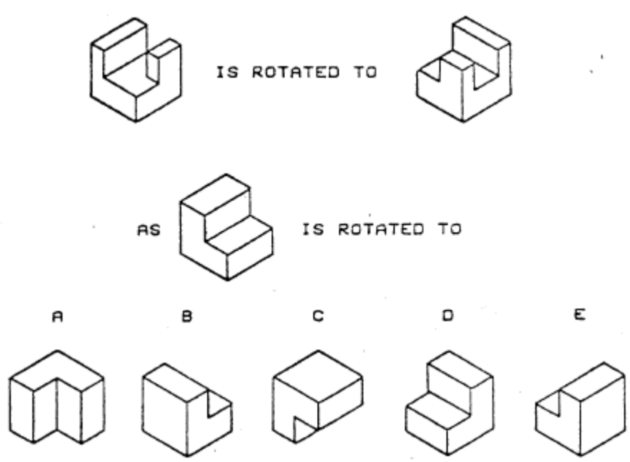

Figure 5. Sample question from ROT assessment. (Bodner et al., 1997)

These assessments, along with others, have been used in a number of studies. Much of the research done in this area focuses on direct intervention to further develop spatial ability within individuals. These studies look at students at the middle school, high school, and college levels, and at mathematics teachers. There is a variety of means in which researchers have attempted to develop spatial ability, all with varied results. However considering most studies found improvements as a direct result of their interventions, it is worthwhile to spend some time considering these different means. It is here that educators can begin to consider the numerous possibilities for instruction and how instruction might need to be modified.

Improving Spatial Ability

One particular study focused on a group of middle school students. This was a small test group of 16 students that were enrolled in an Integrated Technology course at the time. The students spent two to three days a week working on a module developed by Sorby. These modules combined workbook exercises with computer tutorials. The students first began with an introduction of the specific module by the teacher. Then the students completed a computer tutorial in pairs followed by workbook pages. It was found that students preferred working with both the computer software and the workbook. In order to assess the abilities of the students, a modified version of the PSVT:R was administered. The answer choices were reduced from five per question to only three. According to the data collected it seemed the workbook with the software was effective in improving the spatial skills of those students (Sorby, 2009). However, this study was completed with such a small sample size (n=16) that it is difficult to know if similar results would follow with a larger population. In addition, it is not possible to know from the research how these modules were actually implemented. It would be interesting to know how much of the instruction was facilitated by the teacher versus independent learning on the part of the students. How the material is implemented can hold just as much significance as what is contained in the curriculum.

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. These students were assessed a little differently. Their assessment comprised 10 questions from the PSVT:R, 10 questions from the MCT, and 10 questions from the DAT:SR. The data from this study also supported the idea that the materials were effective in improving 3-D spatial skills. However, something interesting from this study was that the gap in gender differences in this study did not seem to decrease: in fact, it may have increased (Sorby, 2009). 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. Before Sorby investigated the skills of middle school and high school students, extensive work was being done at the collegiate level. In 1993, Sorby and Baartnams developed an entire course entitled Introduction to Spatial Visualization with an accompanying textbook. It was a ten week course and was designed to be a pre-graphics course at Michigan Technical University. The text was written to follow the sequence needed to develop 3-D spatial skills. It is important to mention some specifics of this curriculum, as it will have a number of implications for education at the secondary level (Sorby & Baartnams, 2000).

The first week of the course is an introduction and sets up the need for spatial visualization. The second week focuses on isometric and orthographic sketching where students use snap cubes to serve as a tangible models while they learn to sketch. Next the students move into orthographic drawings and applications where the objects have inclined surfaces and standard layouts of engineering drawings are discussed. This is followed up in week four with a focus on pattern development and the use of nets with sheet metal applications (Sorby et al., 2000).

Week five takes students into drawing wireframe geometry as they concentrate on two and three coordinate drawings. Translation and scaling of objects precede the next unit which focuses on rotations. With rotations, students work at sketching isometric views of objects as they are rotated about single and multiple axes. In week eight the students focus on reflections, and week nine deals with cross-sections of solids. The final week extends the material in the previous week by having students develop sketches of solids based on rotating planar figures about an axis (Sorby et al., 2000).

Students who took the Introduction to Spatial Visualization course were assessed using the PSVT:R as a pre- and post-test. In addition, the course was taught six more times. Additional tests were used and further information was gained. As a result of the course, data shows statistically significant gains were made by the students enrolled in the specialized course. Not only did the students score better on these 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.

Although other studies and targeted training at the collegiate level may not have been as extensive as the research of Sorby and Baartmans, they still seem to shed light on other targeted methods of improving spatial ability within students. One such study took place at the University of New Hampshire with a group of freshman mechanical engineering students who were enrolled in a CAD course. Students were given the PSVT, 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 4 hours of training each week. The training consisted of two components, both utilizing types of CAD software (Onyancha et al., 2009).

The first component was the Physical Model Rotator (PMR, see Figure 6), and the second was the Alternative View Screen (AVS, see Figure 7). Students spent two hours a week on each of the two components. The students were given instructions and introductory support with the software, and additional support was available throughout the training sessions. Each session consisted of four activities dealing with items such as the creation of engineering drawings and the rotations of specific views. The PMR software helped students to interpret 3-D objects from the 2-D representations provided. The AVS software provides multiple views of objects and allows for rotation of those objects. Although the training only lasted four weeks, the students were not assessed again until the end of the semester (Onyancha et al., 2009).

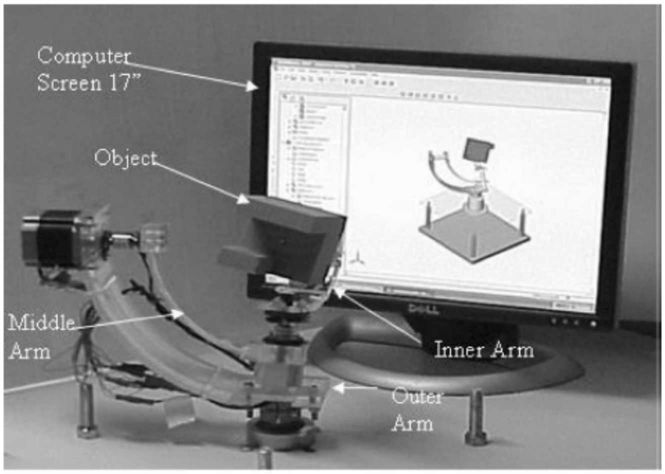

Figure 6. Physical Model Rotator (Onyancha et al., 2009)

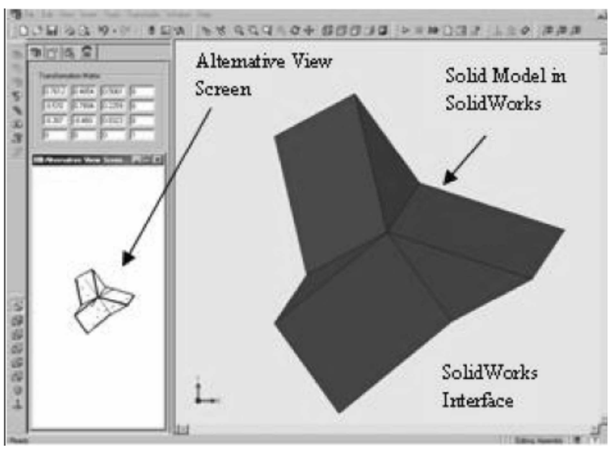

Figure 7. Screenshot of the Alternative View Screen. (Onyancha et al., 2009)

The results certainly favor the targeted training that was implemented. 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. (Onyancha et al., 2009) 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. This was used with a group of Civil Engineering students at the University of La Laguana in Spain. As with the University of New Hampshire, this training was a short time period of only three weeks which required 12 hours worth of work from students. The training was broken into three sessions, each containing eight hours in the classroom followed by four hours of homework. Again, a more detailed look at these sessions is imperative because the content of the training could hold great significance for future instruction (Martin-Dorta et al., 2008).

The first session with the civil engineering students consisted of acquiring basic modeling skills in Google SketchUp (Figure 8). Once students had basic skills, they were instructed to choose a physical part provided and create a 3-D model of it. As a follow up activity, students were asked to create a daily object by taking measurements and developing a 3-D model. Through this process the students began to understand the importance of sketching and dimensions. In the second training session, students were asked to create 3-D models of a part's axonometric projection. At this time there was no direct instruction on orthographic views or perspectives. The third session asked students to create a 3-D model of a part from only the orthographic views. At this time, students did receive a one hour lesson covering the basics of orthographic views. Due to the level of difficulty at this stage, students first worked in groups and then completed some individual reflection. It was during this time that students had to construct a mental image from only the information in the orthographic views. After the training, the MRT and DAT:SR were used to measure the spatial abilities of the students, and the results showed that using Google SketchUp had a definite and positive impact on the spatial ability of the students (Martin-Dorta et al., 2008).

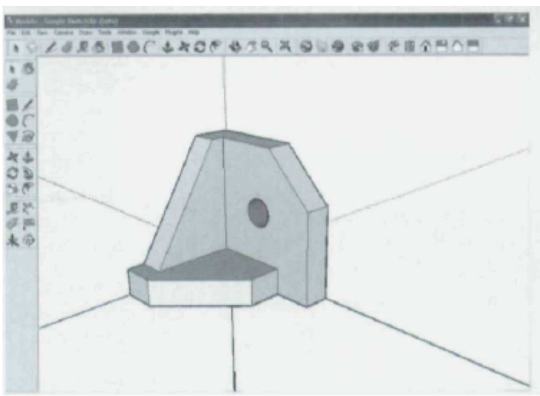

Figure 8. Screenshot from Google SketchUp. (Martin-Dorta et.al, 2008)

Cabri 3D is yet another software program that can be used in developing spatial abilities. This software program (Figure 9) was used on a group of mathematics teachers. The PVST was used as the pre- and post- test measurement tool. For a time period of eight weeks, the teachers completed various activities using Cabri 3D for approximately one and one-half hours each week. As a result, the scores on the test increased, and the data provided evidence that the training with Cabri 3D did in fact contribute to the development of the spatial skills (Guven, 2008).

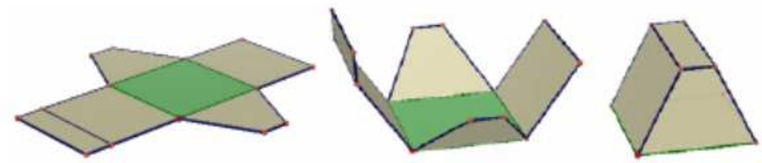

Figure 9. Screenshots of one of the activities step by step. (Guven, 2008)

Thus far the various methods for targeted instruction on spatial ability have included textbook instruction with computer exercises, the Physical Model Rotator, the Alternative View Screen, Google SketchUp, and Cabri 3D. They have also varied in time commitment from an entire semester to only three weeks. 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.

At the University of California at Berkeley, 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. Following the session, the students were assessed again. 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 (Hsi et al. 1997). 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.

Due to the number of studies which have been completed, 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 on how to implement strategies and curriculum which will be most impactful for students and in the end improve spatial ability skills as a whole. Despite the differences among 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.

Implications for Education

As educators ponder which elements to include in instruction, it is important to note that most positive results surfaced from training which included both sketching and the use of 3-D modeling software. Independently these items can be beneficial; however, when combined they allow students to develop deeper spatial ability skills compared to utilizing just one of these elements. The sketching primarily focused on isometric and orthographic views embedded within the curriculum which seems to provide a fairly important standard needed for any spatial ability skill training. However, various 3-D software programs were used to produce 3-D models, all of which seemed to produce positive results. These included programs such as the Physical Model Rotator, the Alternative View Screen, Google SketchUp, and Cabri 3D. As educators consider which software programs to utilize, it is important to consider which programs would require extra training on the part of the teacher as well as the cost. Considering that some of these software programs are free, cost does not need to be an issue.

No matter what sketching exercises or 3-D software is used, it will not make a difference if the delivery by the educator is inadequate. Therefore, it is imperative to consider how an educator will present the material to the students. Much of the research concerning spatial ability discusses the tools and software that was utilized; however not as much attention is given to the rationale behind the pedagogy. There are two primary approaches to teaching spatial ability which most curricula tend to follow. The first is a parts-to-whole approach where there seems to be a logical progression of skills and concepts. For example, instruction would most likely begin with points, and then move to lines and two-dimensional space, and then progress into three-dimensional space and objects. This tends to be more of the traditional route and would be considered more of a drill and practice approach. However, some studies have shown that this approach can still leave a student struggling to visualize 3D objects from the 2D representation (Akasah & Alias, 2010).

On the flip side is the whole-to-parts approach where students begin with 3D representations and progress to 2D detail drawings. Akasah and Alias used this approach when looking at a group of first year civil engineering students. After an initial assessment, the group was divided into a novice group and an expert group. The novice group received six weeks of training in a manual drawing class using the whole-to-parts approach. The expert group was assigned a CAD class. By the end of the six weeks, the novices had essentially caught up to the experts who had two years of training in engineering drawing. The study showed that the whole-to-parts instruction had allowed the novices to catch up to the expert group in the given six weeks (Akasah et al, 2010).

Although the bulk of this research is not focused on the approach to integrating spatial ability skills among students, it is important for educators to understand the two primary delivery methods when it comes to spatial ability. Despite the fact that most curricula regarding engineering drawing use the parts-to-whole approach, this may or may not be the most efficient or effective manner. Nonetheless, if educators are going to implement some form of instruction focused on spatial ability, some time and consideration should also be given to the approach which will be used.

This research clearly supports the idea of targeted training in regards to improving spatial ability. With such a variety of approaches and various software programs, any number of interventions could be implemented. One such software program that has not been discussed is Autodesk Inventor©; however, this study will provide support for the use of such software within an engineering design course in developing spatial ability in high school students.

Summary

As educators in STEM education attempt to improve upon the existing curricula, 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” (as cited in Akasah, 2010). 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, curricula can begin to be evaluated and modified in order to improve the spatial ability of students. As noted throughout research, this can be accomplished in a number of different ways, and it is up to the educators of STEM education 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. Not only is this where students could potentially develop the high abstraction level required for spatial ability tasks, but it is an ideal location within STEM education to not only provide a foundation but also assist other disciplines as they utilize the necessary skills of spatial ability. Therefore, this study focuses on the spatial ability skills of high school geometry students in comparison to those geometry students who are simultaneously enrolled in engineering in order to determine what can be learned from these two groups of students and the curricula to which they are exposed.

Chapter 3: Methods

Overview:

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 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 look at the spatial ability of those students who were solely enrolled in PreAP Geometry versus those that were simultaneously enrolled in Introduction to Engineering Design. In addition to this data, the gender differences among students and spatial ability were analyzed.

Curriculum

The curriculum was the primary factor that differed 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 (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 (Antinone, L., & Whitman, C., 2007). 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 worthy to note 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 when it came to 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 10). At times this meant students took existing isometric and orthographic drawings and created 3D models of the parts. Once the models were created, the students were able to assemble and manipulate the parts to create a full working model 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, it was expected that students were able to not only sketch 2D views and create 3D solids on the computer but also able to transfer back and forth between 2D and 3D representations. The large amount of time devoted to sketching and computer-generated 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 of spatial ability.

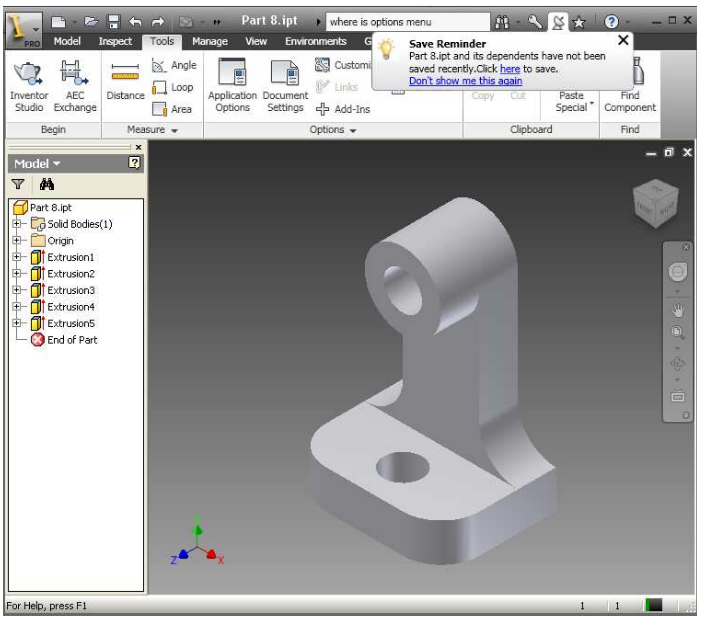

Figure 10: Sample screen from Autodesk Inventor© software.

Although an entire unit was devoted to spatial ability in the PreAP Geometry curriculum, it was evident that very little 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 would make one think that the development of spatial ability would certainly be a byproduct of the classroom curriculum.

Sample

All students involved in this study were enrolled in PreAP Geometry at a large high school (n = 207). They were selected due to their enrollment in PreAP Geometry, which is optional for students. Students can opt to take regular geometry to gain credit for geometry if they prefer. 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 (Figure 12). In addition, the geometry curriculum provided the most content in 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 (Figure 14). There were a total of 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 students chose to take, 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.

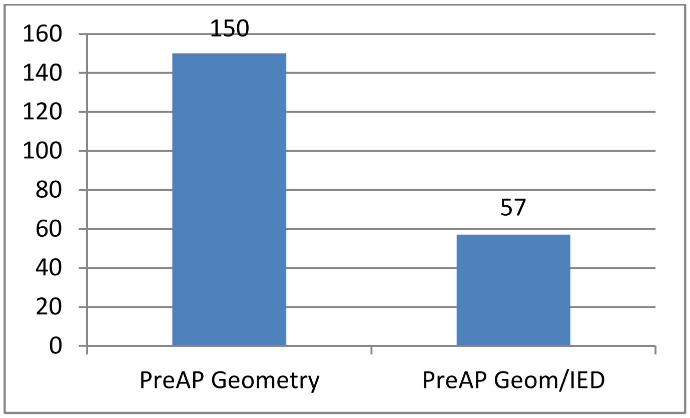

FIGURE 11. Number of students enrolled by class.

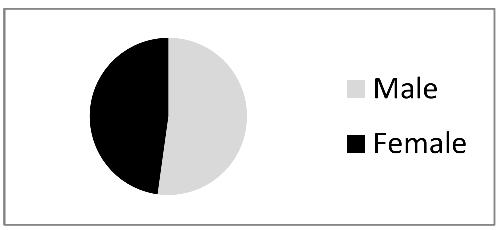

FIGURE 12. Male/Female Enrollment in PreAP Geometry

Assessment

The instrument used to assess the students was the Purdue Visualization of Rotations Test (ROT), a shortened version of the Purdue Spatial Visualization Test of Rotations (PSVT:R) which originally had 30 questions (Sorby et al., 2000). 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, as shown in Figure 13. Refer to the appendix for the full assessment. 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.

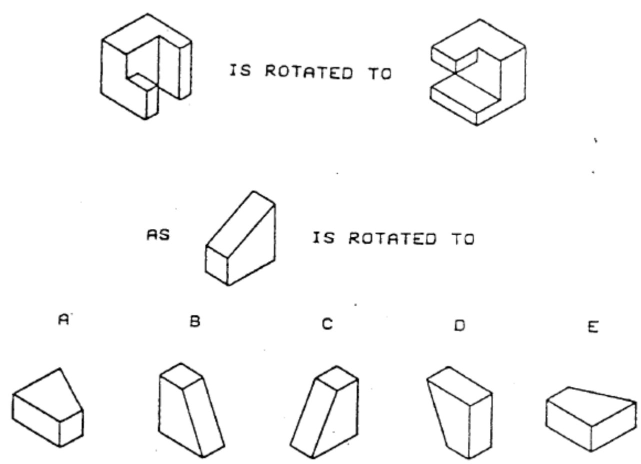

Figure 13. Additional question from ROT assessment. (Bodner et al., 1997)

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 of the 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, with the assumption that was a sufficient amount of time for students to be able to complete the test. Although the level of difficulty on the questions seems to get more challenging as the test progresses, each question was weighted equally. Therefore, the minimum achievement score possible was a zero, and the maximum achievement score possible was a 20.

All exams and answer sheets were collected and given to the researcher. The items were then graded and compiled. The data were graphed to check for normality between each group being compared; however, not all groups had a normal distribution. An independent two-sample t-test was performed using StatCrunch©. 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.

Chapter 4: Data Analysis and Results

As stated previously, 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. The study was conducted with 207 high school PreAP Geometry students near the end of the 2010-2011 academic year with the approval of The University of Texas at Austin Institutional Review Board. The two groups of interest were those students enrolled solely in PreAP Geometry and those simultaneously enrolled in Introduction to Engineering Design. A summary of the statistics for the two groups is shown in Table 1.

Column	**n**	**Mean**	**Variance**	**Std. Dev.**	**Std. Err.**	**Median**	**Range**	**Min**	**Max**
Geometry	150	14.093333	11.857002	3.4434	0.28115243	14	16	4	20
Geometry and Engineering	57	15.245614	11.152883	3.3395932	0.44233993	16	16	4	20

Table 1: Summary statistics for engineering and geometry students.

For the statistical analysis an independent samples t-test was used between the two groups, with 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 getting the results that were obtained. Therefore, the null hypothesis is rejected and we can conclude that the engineering course which incorporated Autodesk Inventor© had a positive and measurable impact on the students or that the students taking engineering were significantly different from those not taking the course.

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. Initially the data were analyzed looking at the entire sample population (n = 207), and then a number of analyses were performed to identify gender differences. 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. Regarding all males (n = 108) in comparison to all females (n = 99), a summary of the statistics is shown in Table 2. 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 = 3.60). Therefore, the data indicates that males were significantly higher in spatial ability than females throughout the entire sample population.

Column	**n**	**Mean**	**Variance**	**Std. Dev.**	**Std. Err.**	**Median**	**Range**	**Min**	**Max**
Female	99	13.686869	12.972377	3.6017187	0.36198634	14	16	4	20
Males	108	15.074074	10.050536	3.170258	0.30505824	16	16	4	20

Table 2: Summary statistics for males and females.

A further look into this difference provides more insight. 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). Table 3 shows these results. 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, that is not what the results showed (Table 4). 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 = 15.889, SD = 1.111) comparable to males enrolled in engineering (M = 15.125, SD = 3.362).

Column	n	Mean	Variance	Std. Dev.	Std. Err.	Median	Range	Min	Max
Females in Geometry	90	13.466666	12.74606	3.5701635	0.3763283	13	16	4	20
Males in Geometry	60	15.033334	9.219209	3.03615	0.39198658	15	15	5	20

Table 3: Summary statistics for males and females only in geometry.

Column	n	Mean	Variance	Std. Dev.	Std. Err.	Median	Range	Min	Max
Female in IED	9	15.888889	11.111111	3.3333333	1.11111112	16	9	11	20
Males in IED	49	15.125	11.303191	3.362022	.48526606	16	16	4	20

Table 4: Summary statistics for males and females in engineering.

Due to this difference a further analysis was performed 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) A summary of the statistics is shown in Table 5.

Column	n	Mean	Variance	Std. Dev.	Std. Err.	Median	Range	Min	Max
Males in IED	48	15.125	11.303191	3.362022	0.4852661	16	16	4	20
Males in Geometry	60	15.033334	9.219209	3.036315	0.3919866	15	15	5	20

Table 5: Summary statistics for males.

In contrast it appears there was a significant difference among females. Again, an 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). A summary of the statistics is shown in Table 6.

Column	n	Mean	Variance	Std. Dev.	Std. Err.	Median	Range	Min	Max
Females in IED	9	15.888889	11.11111	3.333333	1.1111112	16	9	11	20
Females in Geometry	90	13.46666	12.746067	3.5701635	0.3963283	13	16	4	20

Table 6: Summary statistics for females.

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.

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. It is possible the optional enrollment in this higher level course somewhat eliminates a number of extraneous variables. However no data were analyzed regarding the variables such as mathematical ability, motivation, and socioeconomic status. Although these factors may have provided some bias, it most likely did not compromise the results found between the males and females since a number of studies have found similar results with males and females (Martin-Dorta et al., 2008; Sorby et al., 2010). These results only further support previous findings that males tend to outperform females on spatial ability tasks (Hsi et al., 1997; Martin-Dorta et al., 2008; Sorby et al,. 2000; Sorby et al., 2010). In addition, the results also support research where gender differences disappeared after targeted training (Hsi et al., 1997) as seen in this study where females in engineering did not differ much from males in engineering.

Additionally, the means by which the assessment was proctored may hold some significance. According to Bodner and Guay (1997), the best measures of spatial ability are those tests that maximize the gestalt processing and minimize the analytical processing. 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 (as cited in Sorby, 2009) reasoned that females are more analytical and males tend to be more holistic, it could be assumed the gender difference might disappear in this study. Interestingly enough, though, it 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 may definitely play 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, though, 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 attempted to be removed. 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 prevent such a large number of students scoring so high and provide more of a normal distribution of the data. 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.

Chapter 5: Conclusions

The purpose of this study was to look at the importance of geometry education within engineering education along with other disciplines. More specifically, this study focused on the necessary skill of spatial ability. As spatial ability is a skill all students are expected to develop and utilize in geometry, the development of this skill can help bridge the gap between geometry education and other disciplines. With STEM education continually changing and adapting to include the skills necessary for current students to be successful upon completion of secondary and post-secondary education, it is vital that educators understand the importance spatial ability plays in this role.

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 goal was to examine how the students in PreAP Geometry differed from a smaller group within this population who were also enrolled in an engineering design course. The hypothesis stated 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.

The results of this study supported the hypothesis by revealing there was a difference between these two groups of students 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, but 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.

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 (Akasah et al., 2010; Guven et al., 2008; Hsi et al., 1997; Onyancha et al., 2009; Sorby et al., 2000). Therefore, geometry educators need to start considering how such software can be integrated into the curriculum in a meaningful way. If geometry education is going to rise to meet the needs of students today, it should most certainly spend valuable time on developing spatial ability, as it will help students in multiple disciplines. Research shows such a result is possible.

Appendix: Purdue Visualization of Rotations Test

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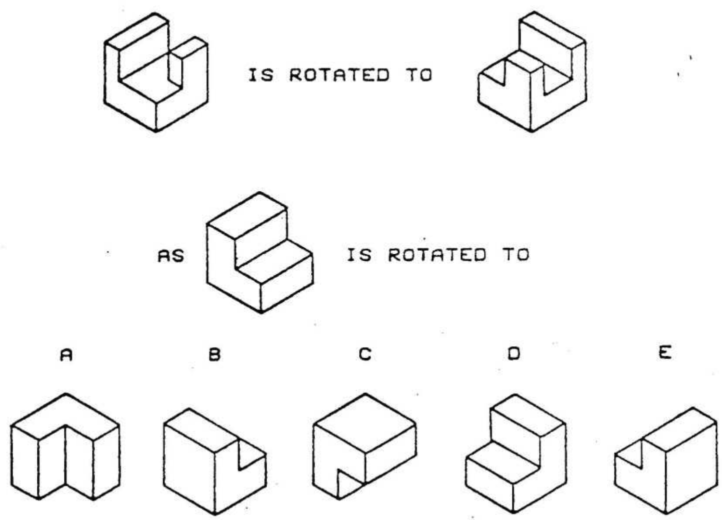
Do NOT make any marks on this exam.
Mark your answers on the separate answer sheet

DIRECTIONS

This test consists of 20 questions designed to see how well you can visualize the rotation of three-dimensional objects. An example of the type of question included in this test is shown below.



For each question, you should:

I. Study how the object in the top line of the question is rotated.

II. Picture in your mind what the object shown in the middle line of the question looks like when rotated in exactly the same manner.

III. Select from among the five drawings (A, B, C, D, or E) given in tbe bottom line of the question the one that looks like the object rotated in the correct position.

What is the correct answer to the example shown above?

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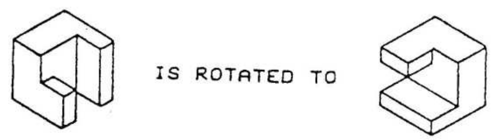
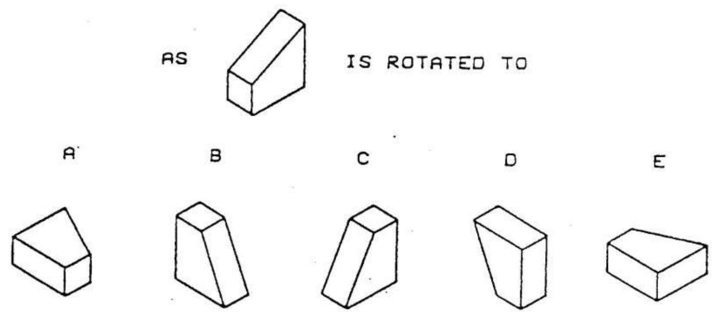
Answers A. B. C. and E are wrong. Only drawing D looks like the object after it hsa been rotated. Remember that each question has only one correct answer.

Now look at the example shown below and try to select the drawing that looks like the object in the correct position when the given rotation is applied





Note that the rotation in this example is more complex. The correct answer for this example is B.

Do NOT make any marks in this booklet.
Mark your answers on the separate answer sheet.
You will be told when to begin

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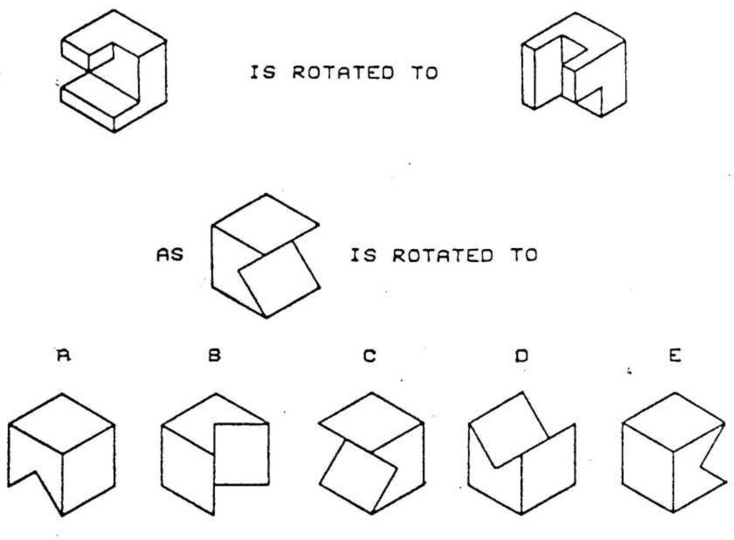

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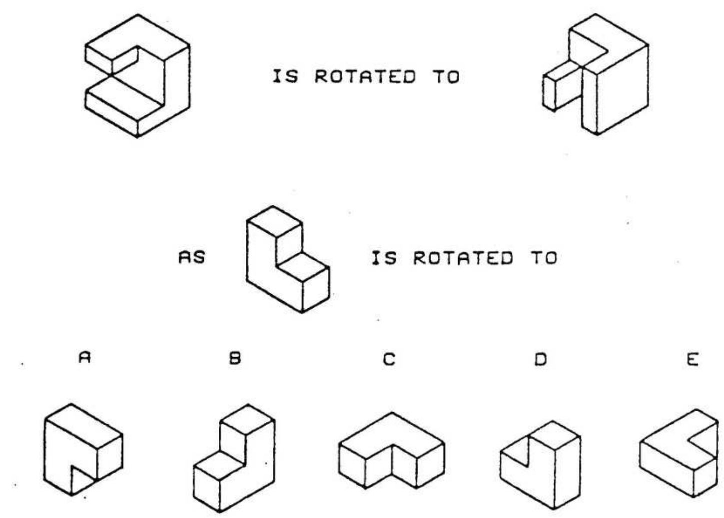

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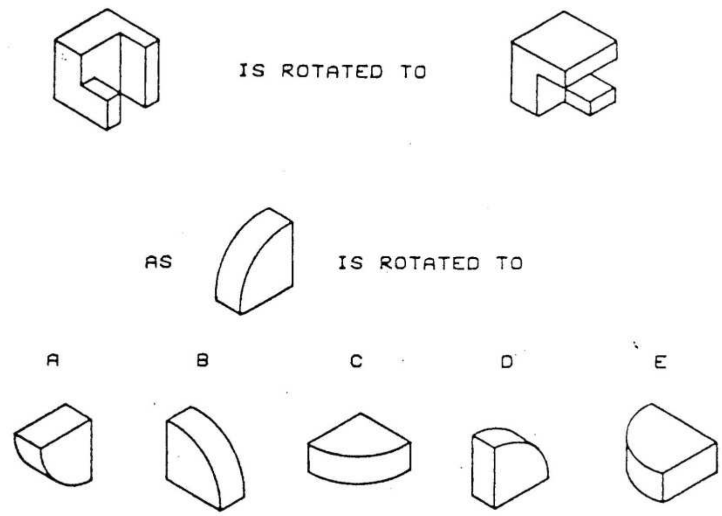

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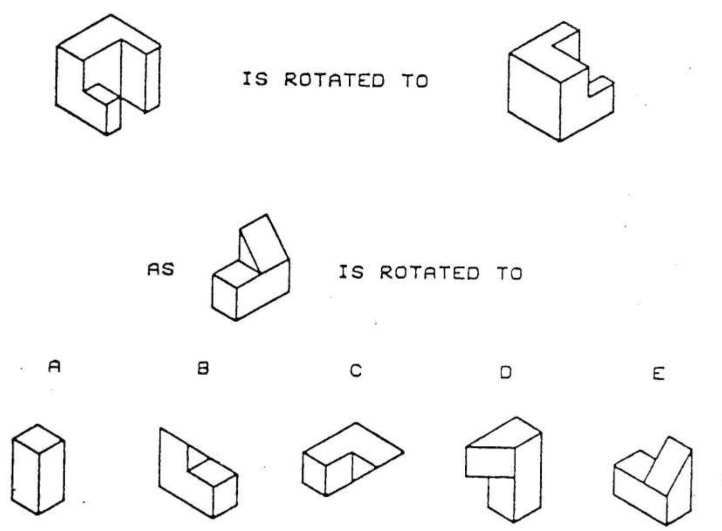

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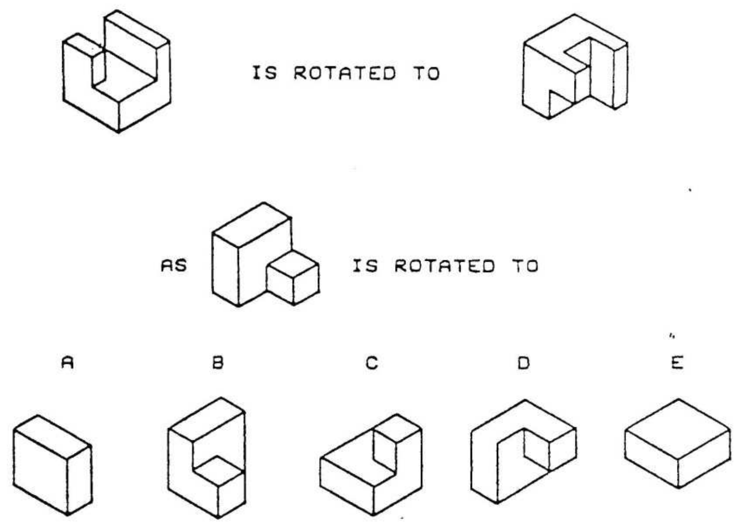

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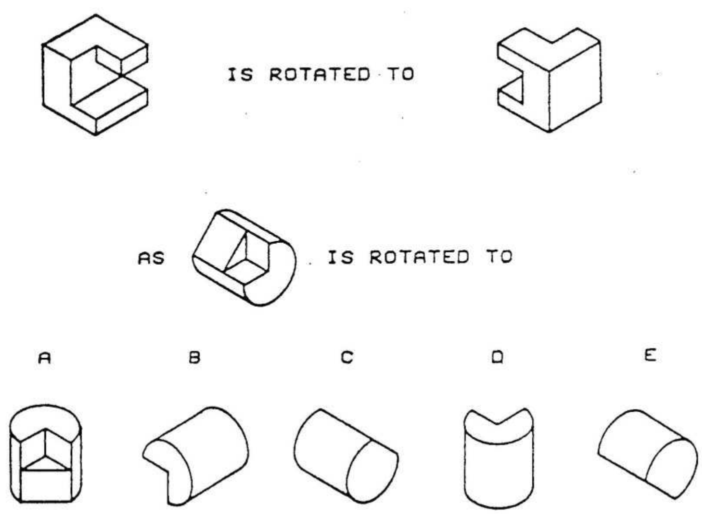

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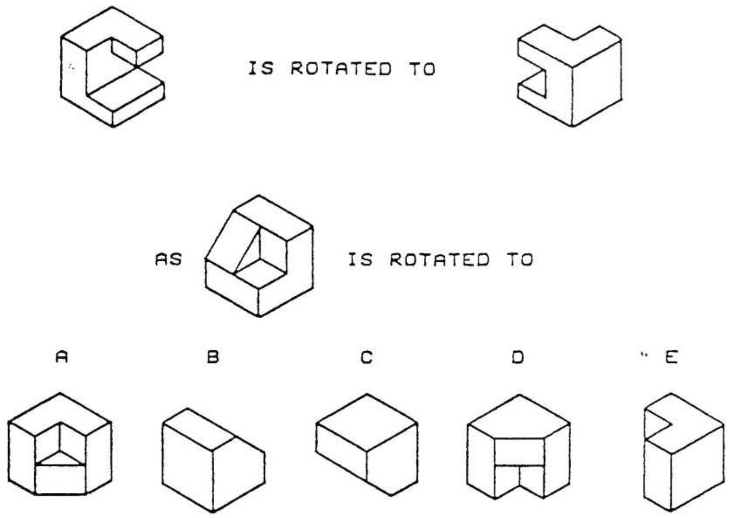

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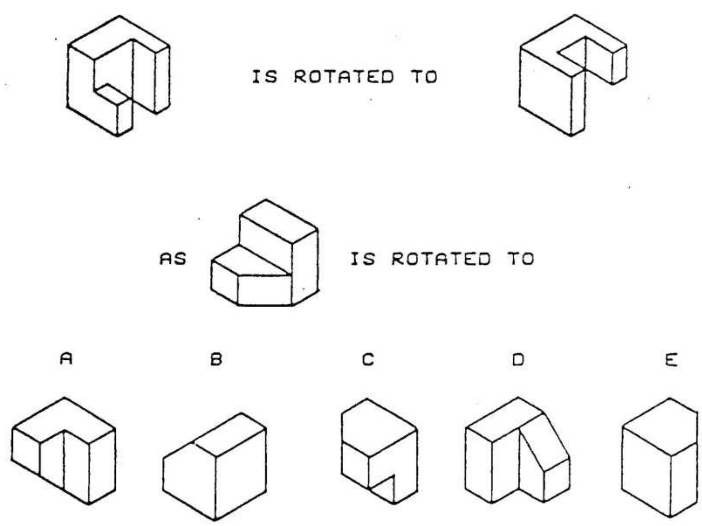

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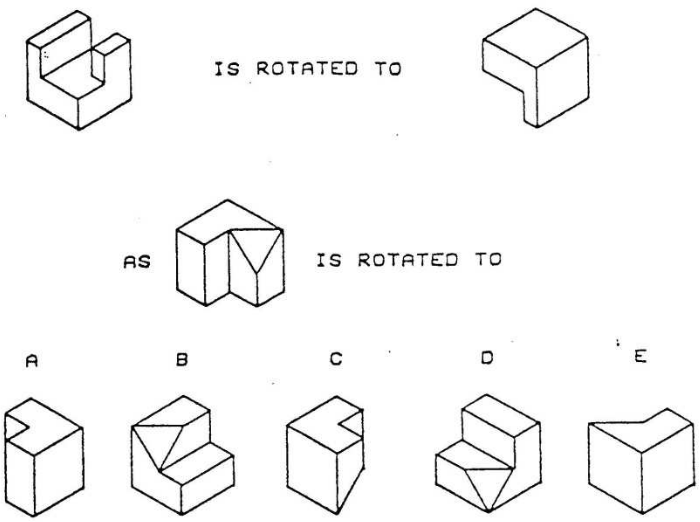

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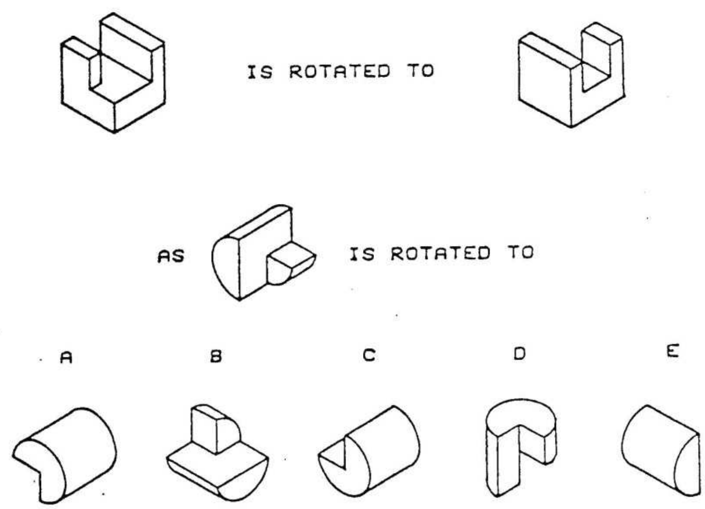

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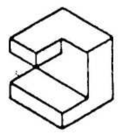
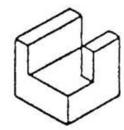
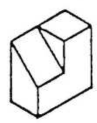
11  IS ROTATED TO 

AS  IS ROTATED TO

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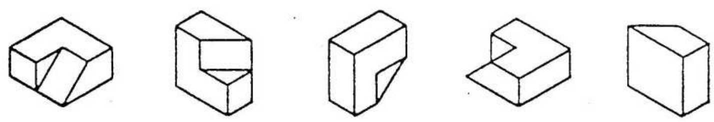
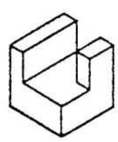
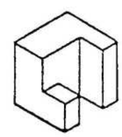
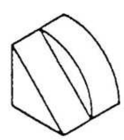


12  IS ROTATED TO 

AS  IS ROTATED TO

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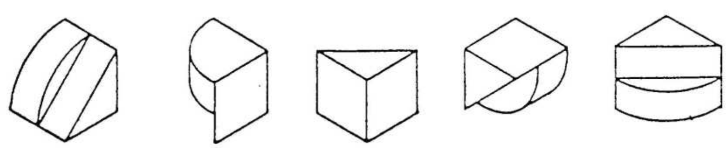

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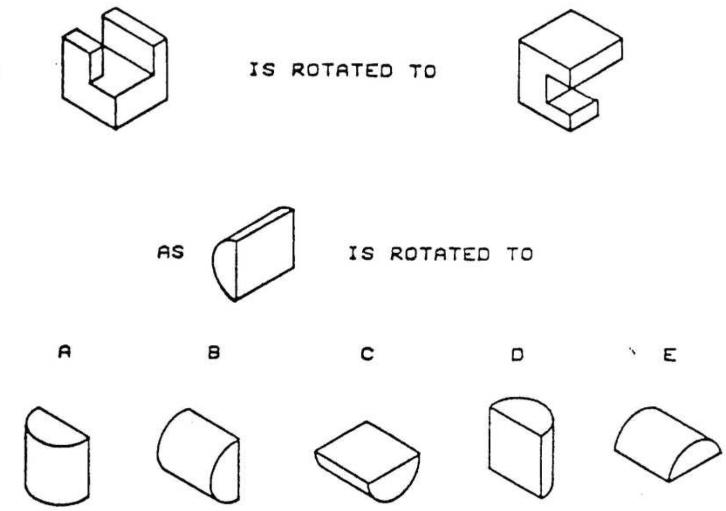

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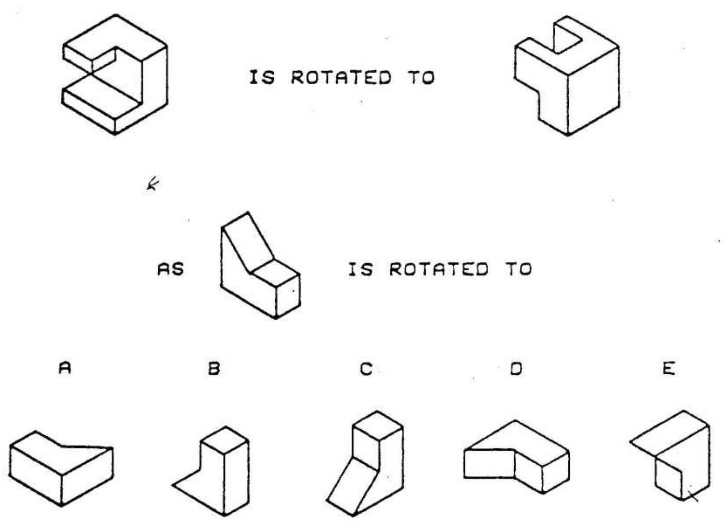

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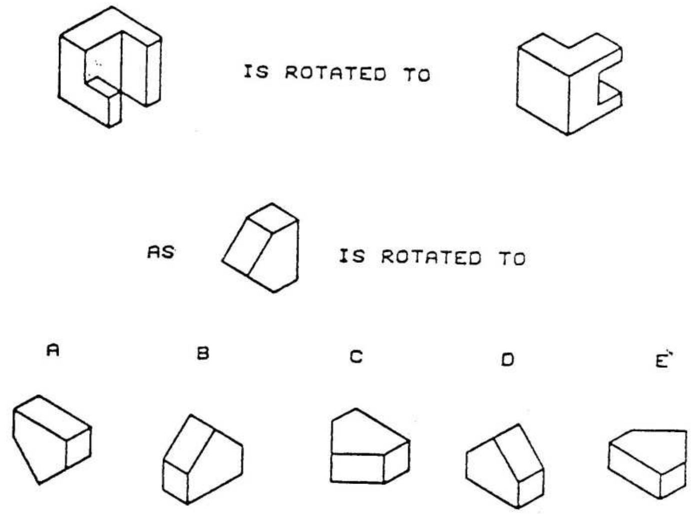

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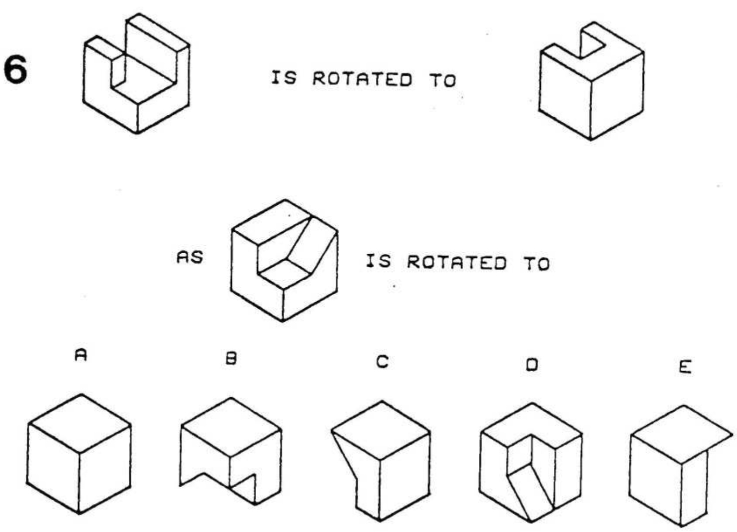

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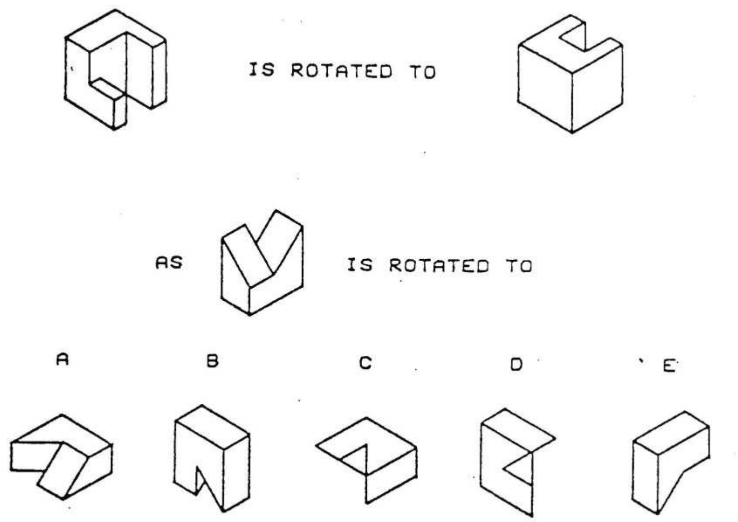

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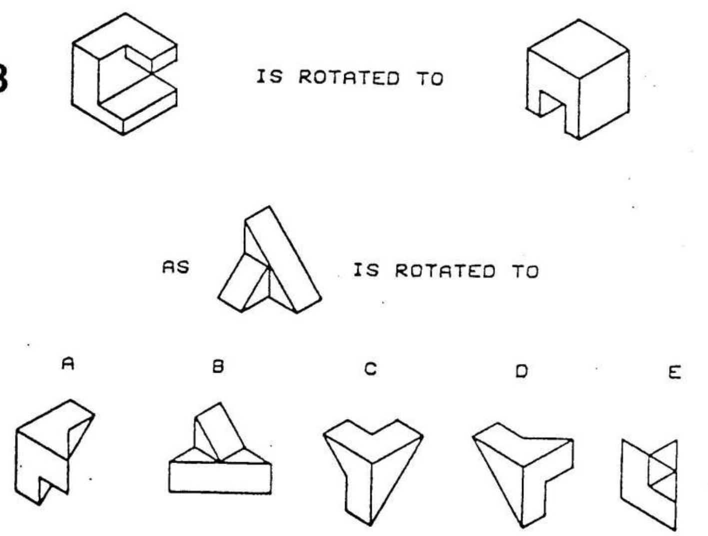

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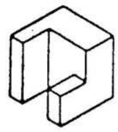
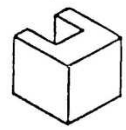
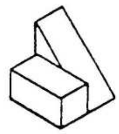
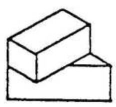
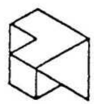
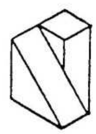
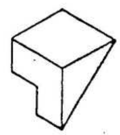
19  IS ROTATED TO 

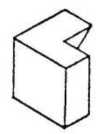
AS  IS ROTATED TO

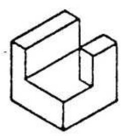
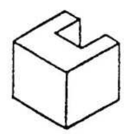
A 

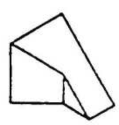
B 

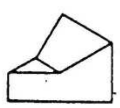
C 

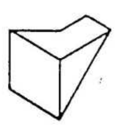
D 

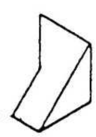
E 

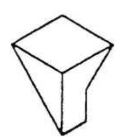
20  IS ROTATED TO 

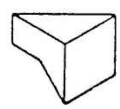
AS  IS ROTATED TO

A 

B 

C 

D 

E 

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Vita

Kristin Brudigam is the daughter of Lee and Mary Brudigam and grew up in Wakefield, Nebraska. She attended Wayne State College in Wayne, Nebraska where she earned her Bachelor of Science in Mathematics Education in 2004. Upon graduation, Kristin moved to Killeen, Texas where she taught and coached at Ellison High School. She then moved to Austin and has been teaching at Lake Travis High School for the past six years.

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