# An Analysis of the Effectiveness of Orthographic Projection Activities in Teaching Spatial Reasoning Concepts to Sixth Grade Students at Greendale Middle School

by

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## Abstract

In the subject of technology education at Greendale Middle School, it is very important for every student to develop spatial reasoning skills at the sixth grade level. Spatial reasoning skills are utilized often when reading or developing designs for fabrication in technology education and engineering classes. Often teachers may simply cover this topic with orthographic projection using two-dimensional (2-D) isometric examples. The utilization of three-dimensional (3-D) computer software was investigated as a means for more in-depth learning of these abilities. Educators who teach technology education or engineering design concepts at any middle school may benefit from this study.

This study used an experimental approach to determine the effectiveness of orthographic projection activities toward developing the spatial reasoning skills of sixth grade students. The

spatial reasoning elements utilized in the learning activities primarily included the categories of mental rotation, spatial perception, and spatial visualization.

These spatial reasoning concepts were taught in a series of 2-D and 3-D sixth grade activities. These activities included object view recognition and identification of 2-D representations matching 3-D shapes. The control group was taught the orthographic projection lessons by using 2-D isometric methods. The experimental group was taught the same lessons using a 3-D software computer program. One final test was administered to both groups in order to evaluate which of the two instructional methods was most effective in student learning of spatial reasoning concepts. It was determined that the students who used the 3-D modeling software scored significantly higher on the final assessment.

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# Chapter I: Introduction

## Background Information

The design process is an important part of the curriculum in any Technology Education course at the Middle School grade levels. Part of that curriculum commonly includes an introduction to orthographic projection as a means to help students develop spatial reasoning skills. Orthographic projection is used to show the detailed information needed to manufacture a specific part. Engineers and designers usually generate a number of detailed drawings to complete a project. Effective instruction of spatial reasoning concepts is essential to any quality Middle School Technology Education program.

Orthographic projection abilities play an important role in learning the concepts of spatial reasoning for students. Orthographic projection activities provide a means to understanding spatial reasoning concepts such as mental rotation as well as spatial relations and visualization. Sorby (2007) reported that children in pre-elementary and early-elementary grades are able to recognize two-dimensional properties like size differences and an object's distance from other objects. Older elementary students are able to perceive different views, or rotations of 3-D objects. At the middle school grade levels, students often have the ability to visualize symmetry, area, volume, and size related to dimensions of an object (Sorby, 2007). Sorby's findings provide a foundation for student experience and understanding of spatial reasoning concepts.

Technology Education teachers commonly introduce orthographic projection through a variety of sketching exercises with two-dimensional (2-D) isometric examples. Students often struggle with orthographic projection concepts when this method is the only means of teaching these concepts (Contero, Naya, Company, Saorin, 2007). Another teaching method incorporates the use of current three-dimensional computer modeling software to help introduce spatial reasoning concepts by completing orthographic projection assignments. Students who have access and utilize computer activities, such as video games, often experience ease in improving their spatial abilities (Feng, Spence, and Pratt, 2007).

Children today are becoming more experienced with computer skills at a younger age than past generations (Shaffer, 2006). Most students today feel completely at ease with their computer use in the classroom (Basham, Kotrlik, 2008). Computer games provide children the opportunity to investigate and manipulate subject matter, often without much real concentration (Shaffer, 2006). Students at the middle school level have more opportunities to work with three-dimensional (3-D) computer modeling software than in the past. Many school technology education labs are equipped with computers that have some form of computer aided design software available for student use. Yet current technology education curriculum programs are developed to teach proper design methodology by using 2-D isometric sketching exercises to learn basic orthographic projection concepts (Mathewson, 1998). When students are introduced to orthographic projection, primarily through sketching exercises using 2-D isometric examples, there is often a certain level of discomfort for those students who lack confidence in identifying proper multi-view principles.

**Statement of the Problem**

Currently the sixth grade students at Greendale Middle School are introduced to orthographic projection concepts primarily with 2-D isometric models to complete various sketching assignments. Many of the students struggle learning these concepts with this method of instruction. While 3-D computer modeling software is now available, teachers may not utilize it in orthographic projection lessons for further students understanding of spatial reasoning concepts. Therefore, with the addition of using 3-D computer modeling software as the primary tool for examining 3-D samples to complete orthographic projection sketches, this study will examine evidence as to whether or not students are able to better understand spatial reasoning concepts with this method.

**Purpose of the Study**

The purpose of this study was to investigate how effectively current orthographic projection activities teach spatial reasoning concepts at the 6$^{th}$ grade level at Greendale Middle School. This study also investigated how effective three-dimensional computer modeling software methods teach spatial reasoning concepts. More specifically, the goal was meant to determine which is the more effective instructional method in teaching spatial reasoning concepts.

**The following research questions will guide this study:**

1. How effective are two-dimensional isometric orthographic projection activities used to teach sixth grade students spatial reasoning concepts?
2. How effective are three-dimensional computer modeling software methods in learning basic spatial reasoning concepts?
3. What is the most effective instructional method in teaching sixth grade students spatial reasoning skills?

**Definition of Terms**

**Constructivism** - a theory of knowledge that promotes how humans utilize their connections between ideas and experiences to construct knowledge and understanding through meaningful tasks.

**GTT** - Gateway To Technology® is an activity-oriented middle school curriculum designed to help students in grades six through eight explore math, science, and technology. There are five independent, nine-week units; schools are expected to offer a minimum of two units, Design and Modeling™ and Automation and Robotics™. (Newberry, 2008, p.3)

**Isometric View** – A three-dimensional representation of an object in a two-dimensional format.

**Mental Rotation** - The ability to recognize a new position of a rotated object.

**Orthographic Projection** – A design concept used for multi-view drawings for objects that primarily consist of the top, front, and right side views. These views and the details are placed in alignment on the drawing.

**PLTW** - Project Lead The Way® (PLTW) is a not-for-profit organization that promotes pre-engineering courses for middle and high school students.

**Rote Learning** - A learning technique that focuses on memorization along with repetition and recall.

**Three-Dimensional Computer Modeling Software** – Computer software used to design three-dimensional objects. In this case study, this software will be used to have students rotate objects to view proper sides and line-types relative to orthographic projection.

**Spatial Perception** - The ability to recognize the spatial relationships between two objects.

**Spatial Reasoning** – The ability to visualize, perceive, and manipulate objects mentally

**Spatial Visualization** - The ability to recognize an image and its modifications.

**Methodology**

This study was designed to research student learning of spatial reasoning concepts using orthographic projection activities. Two instructional methods were utilized in this experiment. The initial method involved 2-D isometric object representation lessons. The second method involved 3-D software object modeling lessons. A final assessment was administered to evaluate which of these learning processes was the most effective method of teaching orthographic projection concepts to help students understand spatial reasoning. This experiment was conducted with two sixth grade Technology Education classes at Greendale Middle School.

The contol group was instructed by the traditional 2-D methods often used in Middle School Tech Ed curriculum. The 2-D instructional methods use isometric object samples with the intent of having students identify different views of that object. The experimental group was instructed by using 3-D computer software modeling methods to examine and understand spatial reasoning and orthographic projection concepts. The students began these learning activities with mental rotation activities that included how to identify the rotation of two and three dimensional objects and the matching of images. The spatial perception and visualization activities included how to identify parts of specific shapes, the identification of similar shapes, and the recognition of shapes from different views. Then a final assessment was administered to both groups that was identical in items, format, and concepts measured. The assessment consisted of fifteen items, each worth one point. The data gathered was analyzed to form a basis for conclusions and recommendations.

# Chapter II: Literature Review

The purpose of this study was to investigate how effectively current traditional orthographic projection activities teach spatial reasoning concepts at the $6^{th}$ grade level at Greendale Middle School. This study also investigated how effectively three-dimensional computer modeling software methods teach spatial reasoning concepts. More specifically, the goal was to determine which is the more effective instructional method in teaching spatial reasoning concepts. The following review of literature provides documentation of past studies that relate to student learning of spatial reasoning concepts.

## Introduction

In the subject of Technology Education at Greendale Middle School, sixth grade students often struggle when learning spatial reasoning concepts through orthographic projection methods. Orthographic projection methods focus on the drawing practices of properly creating a multi-view technical design of an object for fabrication. The design must include enough information so that any skilled tradesperson could fabricate the object. These methods include, but are not limited to, the ability to draw different angles or views (top, front, and right side) of the object, the proper placement and alignment of the views on a drawing, the correct types of lines to include in a drawing, and the proper dimensions to include in a drawing. These methods have been used to develop students' spatial reasoning skills of mental rotation, spatial perception and visualization (see Donohue, 2010; Sutton and Williams, 2008). Mental rotation refers to the identification of a different view of a two-dimensional (2-D) or three- dimensional (3-D) object that has been rotated from a certain position. Spatial perception relates the identification of spatial relationships between two objects, in most cases between an object and examples of similar objects, which are included as a distraction. Spatial visualization refers to the identification of an image that has been distorted or manipulated by twisting or inverting the sample image (Donohue, 2010).

**Spatial Reasoning and Engineering Education**

The development of spatial reasoning ability is a key component in understanding most concepts of Engineering and Technology Education. Middle school students in Technology Education/Engineering classes may need to develop their skills in spatial reasoning possibly prior to, as well as during, the actual orthographic projection exercises. Sutton and Williams (2008) asserted that students often have a better grasp of spatial reasoning concepts after they successfully work through orthographic design problems. Sutton and Williams (2008) communicated the importance of recognizing that spatial reasoning is the primary learning objective for students participating in engineering related activities like orthographic projection. There may be no widely accepted assessment tool that measures true spatial abilities relating to engineering.   However, there is acceptance that spatial reasoning skills promote an ease of understanding design concepts (see Sorby, 2007; Basham and Kotrlik, 2008).

Ullman (1990) explained that drawing or sketching activities help promote student understanding of spatial reasoning skills. When a student visualizes an object and must represent this object on paper, drawing or sketching the object has often provided further insight relative to how the final object will look. Providing sketching activities as one instructional method of teaching orthographic projection can benefit student understanding of spatial reasoning concepts (Contero, Naya, Company, Saorin, 2007). The research supporting the need for spatial reasoning concepts to be taught as a part of an engineering design curriculum is significant (see Sorby, 2007; Sutton & Williams, 2007; Basham & Kotrlik, 2008). Teachers commonly have introduced lessons that promote spatial reasoning through the use of two-dimensional isometric views that include sketching activities to introduce technical drawing skills (Contero et al., 2007). Isometric view refers to a three-dimensional representation of an object in on a two-dimensional medium. Computer models can be manipulated as true three-dimensional objects with the use of 3-D computer modeling software. The user of this software has the ability to produce orthographic projections, or multi-view technical designs. The software allows the user to utilize many tools and options made available to complete a design efficiently.

**Theory Base**

Constructivist theory posits that students construct meaning and learning over time (Brooks & Brooks, 1993; Hwang, Su, Huang, & Dong, 2009). More specifically, students will construct meaning based on previous experiences and new learning is then connected to past experiences. Said differently, new knowledge is constructed when a student connects their past with what they are asked to learn.

Educators operating under the Constructivist paradigm believe this way of teaching and learning can change the environment of a classroom and enable children to learn most effectively. Indeed, traditional academic activities, where students are required to mimic or repeat back new information provided by the teacher, are abstracted from their settings and mastered by the child in isolation from the main currents of his life. These activities in turn seem disconnected and artificial. As a consequence, the student does them in a rote manner with a disappointing level of achievement (Bobbit, 1934). The experiences of the learner are the key element in Constructivism as they encourage individualized meanings to be formed and problems to be solved in a more personalized way (Simspon, 1996).

Contemporary research regarding Constructivism suggests teaching and learning can occur on a continuum (Vermette, Foote, Bird, Mesibov, Harris-Ewing, & Battaglia, 2001).

Specifically, teachers may simply take the approach of asking students more open-ended questions, rather than simply filling in blanks or finding definitions. However, it has also been suggested that students be placed in control of their entire learning experience by designing curriculum and presentations (Brooks & Brooks, 1993). Indeed, in a completely Constructivist classroom, teachers could act more like facilitators. Rather than being presented with directions and instructions about projects and experiments by teachers, students would be required to simply go it alone. In the end though, researchers are suggesting a middle ground may be the best approach. This would involve a combination of lecture, group projects and open-ended questions where teachers still maintain a degree of control over the curriculum (Howard, McGee, Schwartz, & Purcell, 2000).

As evidenced in Chapter 1, an increasing amount of technology being available in classrooms has spawned a renewed interest in Constructivism. Although it has been found that technology can engage students in a personal way (Prater, 2001), in doing so, educators run the risk of students becoming so involved with technology that the concept central to the lesson is lost (Earnon, 2006).

**Teaching and Learning of Spatial Reasoning Concepts**

Sutton and Williams (2008) explained that many students have difficulties learning the spatial reasoning concepts through orthographic projection with two-dimensional isometric sketching activities used as the primary teaching method. Students often continue to struggle with these sketching activities due to the lack of spatial reasoning concepts taught in these lessons. Instructors often use curriculum that almost exclusively utilizes isometric samples as the primary method of instruction with minimal spatial ability concepts covered or connections made relative to spatial reasoning (Contero et al., 2007). Orthographic projection curricula frequently supports lessons that teach spatial reasoning concepts by using basic two-dimensional media, including isometric drawing examples, and then introduce the use of three-dimensional modeling software programs as a final design activity or project. This method is commonly promoted in textbooks as well as curriculum documents (Wright 2004). Many lessons provided in current engineering and technology textbooks primarily use isometric two-dimensional techniques in their instructional methods (Wright, 2004). One contemporary approach to this method can be found in a curriculum titled Project Lead the Way (PLTW). PLTW is a not-for-profit organization that promotes pre-engineering curriculum for middle and high school students (Project Lead the Way Inc., 2009). As part of this particular approach, the students primarily work with two-dimensional isometric samples to complete orthographic projection drawings in order to learn spatial reasoning concepts. Students are often prompted conclude the unit with a three-dimensional software design project included in the PLTW program. However, the 3-D modeling software is seldom utilized prior to the culminating activity (Contero et al., 2007).

**Three-Dimensional Software**

Willis (2006) advocated for the use of computers to spark student interest in learning. Mathewson (1998) explained that teachers must provide much more dynamic lessons in order to compete with the accessibility of today's technology. Mathewson (1998) also noted that with this quick, modern availability of updated on-line media activities, educators will find it more difficult to pique students' interests and motivation with traditional sketching and drawing activities to promote spatial reasoning skills or abilities. Willis (2006) stated that student learning relies heavily on student interest and is reinforced if students get the chance to physically or virtually experience the actual learning concepts. Computer software activities keep students interested in the subject matter of spatial reasoning relative to orthographic projection

(Sorby, 2007). Ware (2001) found that spatial reasoning could be improved if training with appropriate materials is provided. He explained that some studies indicate that the use of computer software can be a significant factor in improving student ability to learn spatial concepts. This would suggest that computer usage may provide motivation for student learning because students enjoy computer interaction. Indeed, Contero, et al. (2007) as well as Sutton and Williams (2007) verified the points that spatial reasoning concepts that are taught using orthographic projection design skills should have not only a two-dimensional sketching component, but also a three-dimensional modeling software component. Contero, et al. (2007) further explained that even though 3-D software has been included in recent orthographic design curricula, it is primarily used to accent the traditional lessons as a culminating activity or as a final design project. Contero's study communicated that very few textbooks or curricular guides promote 3-D software as a primary method of instruction in teaching the spatial reasoning concepts of orthographic projection. Sutton and Williams (2007) explained that the traditional 2-D isometric sketching approach to teaching these spatial ability skills often results in memorization learning techniques. In other words, this traditional approach of using primarily 2-D isometric samples provides students with minimal hands on experience and the lessons tend to encourage a rote learning method of instruction. Rote learning may effectively teach students simple examples such as the basic views in an orthographic projection, but can be unreliable for more complex spatial concepts. Sutton and Williams go on to explain that most students experience very little education regarding spatial reasoning skills. Often students are left in the position of using their natural ability to decipher specific views of objects from various perspectives. Most design curricula, even in the upper grade levels, involve students in drawing or sketching 3-D objects in a 2-D orthographic projection format. The connection between sketching these projections and incorporating spatial skills to designing real objects is often lost.

It stands to reason that when teaching spatial reasoning concepts specifically related to orthographic projection to middle school level students, incorporating the use of 3-D modeling computer software along with sketching activities in the early stages of learning these concepts could enhance spatial reasoning understanding. It was demonstrated in a study by Sorby (2007) that proper CAD (computer aided design) and technical drawing instruction are equally important in the development of students' spatial abilities. The results of this study indicate that students' spatial reasoning skills consistently improved since the modifications of this course were introduced in 1993. Shaffer (2006) described that children use computer simulated models every time they play video games, so it stands to reason that the use of computer simulations may help students learn. Students also stay more attentive to educational tools that pique their interest. Attentive students learn better (Wolfe, 2001). Shaffer (2006) also explained that computers let us work with simulations all around us. The use of computer-based simulations has been recognized as a powerful tool to stimulate students to engage in the meaningful learning activities and to construct meaningful knowledge (Hwang et al., 2009). Children of the current generation have had experience with computers their whole lives. Teachers who utilize computer software to assist in the teaching of orthographic projection will have students who embrace the learning activities, which may result in better student understanding of spatial reasoning concepts.

# Chapter III: Methodology

## Introduction

The purpose of this study was to investigate how effectively current traditional orthographic projection activities teach spatial reasoning concepts at the 6th grade level at Greendale Middle School. This study also investigated how effectively three-dimensional computer modeling software methods teach spatial reasoning concepts. More specifically, the goal was to determine which is the more effective instructional method in teaching spatial reasoning concepts. The following methodology provides a description of how the study was conducted.

## Research Design

This study was designed to research student learning of spatial reasoning concepts using orthographic projection activities. Two instructional methods were utilized in this experiment. The initial method involved 2-D isometric object representation lessons. The second method involved 3-D software object modeling lessons. A final assessment was administered to evaluate which of these learning processes was the most effective method of teaching orthographic projection concepts to help students understand spatial reasoning.

## Population and Sample

The population of this pilot study was sixth grade students enrolled in the required technology education at Greendale Middle School for the 2010/2011 school year. The sample consisted of two Greendale Middle School sixth Grade fourth quarter classes, which represented 25% of the sixth grade student population. The sample consisted of 18 female students and 32 male students. The control group had 10 female students and 14 male students. The experimental group had 8 female students and 18 male students.

**Instrumentation**

The treatment of this study began with an introductory lesson about mental rotation (Refer to Appendix C). Then the students worked on introductory view recognition assignments using orthographic projection exercises in 2-D or 3-D format (Refer to Appendices D & E). Then the students participated in a more advanced assignment (Refer to Appendix F & G) using spatial reasoning and orthographic projection activities. Lastly, the final test was administered (Refer to Appendix H) that consisted of 15 items worth one point each. These items included drawings or pictures that required the students to choose between correct or incorrect rotations, isometric views, or orthographic projections. Other items required the students to sketch missing views or orthographic projections. Correct answers or sketches indicated a student's understanding of spatial reasoning. The items mentioned above, along with supporting activities and instructional methods, were developed from examples in the literature concerned with spatial reasoning (see Chapter 2) and lessons already being utilized at the $6^{th}$ grade level at Greendale Middle School.

**Data Collection Procedures**

Students were divided into a control group that did all 2-D activities and an experimental group that utilized the 3-D modeling software. The first student learning activity was an object rotation recognition sheet that consisted of four object rotation activities. All students completed this introductory activity. The second activity required the 2-D control group to participate in a 2-D orthographic sketching lab packet that consisted of five drawing activities. A multi-view activity sheet was also administered to the 2-D control group that consisted of eight view identification questions. For the 3-D experimental group, the second activity required them to participate in a 3-D orthographic sketching lab packet that consisted of five drawing activities. These students used the Inventor 3-D modeling software to rotate and examine the objects. The third learning activity required the 2-D control group to complete an orthographic projection exercise sheet that consisted of three, 2-D isometric samples that required the students to sketch the orthographic projections.

Meanwhile, the third learning activity for the 3-D experimental group required them to utilize the Inventor 3-D modeling software to rotate and examine the 3-D object samples to sketch the orthographic projections. Throughout the study, the teacher circulated about the room and collected each drawing assignment when the students completed them. The students raised their hands when an assigned drawing was completed. As mentioned above, a final assessment was administered to both groups that was identical in items, format, and concepts measured. Each student brought the test to the instructor when he or she was finished.

**Data Analysis**

Two instructional approaches were compared. Specifically, lessons utilizing the drawing of 2-D isometric objects were used when teaching the students in the control group while 3-D computer object modeling lessons were used with each experimental group. As described in the instrumentation section above, an identical final assessment covering spatial reasoning concepts was administered to both groups in order to make a determination as to which instructional method is more effective. In addition, supporting evidence in the form of question and answer sheets and sketches produced during the lessons, were also collected. Each of the 15 items on the final assessment was analyzed to determine how well both groups scored on each item compared to one another, in addition to comparing the total number of correct answers for each group on the final assessment as a whole. The performance of each group on each of the learning activities was analyzed in terms of the total number of correct answers for each assignment, and was deemed to be supporting evidence for the conclusions drawn from the results of the final assessment. This numerical information was then translated in percentages, which in turn were presented in tables in Chapter 4.

**Limitations**

The main limitation of this study in terms of being able to apply its findings more widely to other districts and classrooms is the relatively small number of students participating in the study, as well as the unique considerations of a suburban classroom.

Also it should be considered that the utilization of the two experimental groups occurring during different times of the day may affect student performance. The time of day when the experiment is administered was taken into account to select the two classes participating in the study. Klein (2004) indicated that there is a significant decline in student achievement after the mid-to-late morning recess as well as during the early afternoon hours. Student achievement levels vary significantly throughout the hours of the school day (Klein, 2004), which made it important to conduct this experiment with two classes at a close time proximity. Two classes that were directly next to each other ($2^{nd}$ & $3^{rd}$ hours) during the school day were chosen because studies show that middle school student achievement is most successful during the mid-morning (10:00) time frame, prior to a break or recess (Klein, 2004).

# Chapter IV: Results

## Purpose

The purpose of this study was to investigate how effectively orthographic projection activities teach spatial reasoning concepts at the 6th grade level at Greendale Middle School. This study also investigated how effective three-dimensional computer modeling software methods teach spatial reasoning concepts. More specifically, by comparing student performances, the more effective instructional method for teaching spatial reasoning concepts was to be determined. The following data analysis will be used to determine how successful each method described above was at teaching spatial reasoning concepts.

## Introduction

Technology education teachers at Greendale Middle School commonly cover spatial reasoning with two-dimensional isometric examples and utilize 3-D computer modeling software as a culminating activity. This study employed an experimental approach in an effort to determine the effectiveness of orthographic projection activities on developing the spatial reasoning skills of sixth grade students. One instructional method utilizes 2-D isometric samples to guide student learning. The other instructional method utilizes 3-D computer samples to guide learning. The spatial reasoning concepts of mental rotation, spatial perception, and spatial visualization were addressed in a series of two-dimensional and three-dimensional sixth grade activities. Two sixth grade classes, which represent 25% of the sixth grade student population at Greendale Middle School during the 2010/2011 school year, participated in this study. The sample was 18 female students and 32 male students. The control group had 10 female students and 14 male students. The experimental group had 8 female students and 18 male students.

**Methodology**

The contol group was instructed by the 2-D methods often used in Middle School Technology Education curriculum. Two dimensional instructional methods use isometric object samples with the intent of having students identify different views of that object. The experimental group was instructed by primarly using 3-D computer modeling methods to examine and understand spatial reasoning and orthographic projection concepts. During these lessons, the students were asked to complete activities that included a series of spatial reasoning assignments. Specifically, mental rotation activities included how to identify the rotation of two and three dimensional objects and the matching of images. The spatial perception and visualization activities included how to identify parts of specific shapes, the identification of similar shapes, and the recognition of shapes from different views.

**How effective are two-dimensional isometric orthographic projection activities used to teach sixth grade students spatial reasoning concepts?**

This study began with the instructor providing the students with an introductory lesson about object rotation and orthographic projection as well as their importance relative to learning spatial reasoning skills. Both groups completed the Object Rotation Recognition sheet (Refer to Appendix C) to obtain information about the students' general mental rotation ability, which consisted of four items, each worth one point. Neither group used computer assistance for this introductory lesson. The scores for students in each class were totaled and then divided by the number of participants to find the average score for the group. This score was then divided by the maximum score possible to obtain a group percentage.

Table 1

*Object Rotation Recognition Assignment Success Rate*

| Student Population | Control Group | Experimental Group | Difference of Experimental to Control Group |
|---|---|---|---|
| Female | 87.50% | 84.38% | -3.12% |
| Male | 78.57% | 86.11% | +7.54% |
| Total | 83.04% | 85.24% | +2.20% |

As evidenced by the percentages in Table 1, the vast majority of the students were able to answer the items on the object rotation recognition assignment with an accuracy above 83%. The difference between the classes as a whole were very small (2.2%), suggesting that the spatial reasoning abilities of both classes were quite similar prior to the introduction of computer modeling software as an instructional method. A more interesting difference occurs when the difference between genders is noted. Specifically, the females taught using 2-D methods did better on the assignment than the females taught using the 3-D treatment. However, males taught using 3-D instruction scored higher than the males in the control group.

**How effective are three-dimensional computer modeling software methods in learning basic spatial reasoning concepts?**

The first assignment, following the introductory lesson, dealt with the effectiveness of traditional isometric modeling samples to learn basic spatial reasoning and orthographic projection design concepts. To address this topic the researcher provided assignments for the students to sketch orthographic projections of objects by referring to an isometric representation of the objects. The control group was instructed using 2-D methods often used in Technology Education curriculum to complete the same Orthographic Sketching Lab sheet (Refer to Appendix D). Instructional methods used with the experimental group employed 3-D computer modeling software to complete the same Orthographic Sketching Lab sheet (Refer to Appendix E) that consisted of five items, each worth one point.

Table 2

*Orthographic Sketching Assignment Lab Success Rate*

| Student Population | Control Group | Experimental Group | Difference of Experimental to Control Group |
|---|---|---|---|
| Female | 70.00% | 77.14% | +7.14% |
| Male | 74.29% | 78.46% | +4.17% |
| Total | 72.14% | 77.80% | +5.66% |

As evidenced in Table 2, all students were able to answer items on the orthographic sketching assignment lab with an accuracy of at least 70%. Both males and females in the experimental group performed better than students in the control group. Specifically, females scored 7.14% and males 4.17% higher when instruction utilizing 3-D software was employed.

The next assignment dealt with the effectiveness of 3-D computer modeling methods to learn basic spatial reasoning and orthographic projection concepts. To address this topic the researcher provided assignments for both groups using the same objects. The students in the control group completed an Orthographic Projection Exercise Sheet (Refer to Appendix F). The experimental group, with the use of 3-D computer modeling software, completed the 3-D

Software Orthographic Drawing Exercise Sheet (Refer to Appendix G) that consisted of nine items, each worth one point.

Table 3

*Orthographic Projection Exercise Sheet Success Rate*

| Student Population | Control Group | Experimental Group | Difference of Experimental to Control Group |
|---|---|---|---|
| Female | 51.85% | 85.19% | +33.34% |
| Male | 69.84% | 86.11% | +16.27% |
| Total | 60.85% | 85.65% | +24.80% |

As seen in Table 3, the control group scored much lower than the experimental group, with females answering nearly half of the items on the orthographic projection exercise sheet incorrectly. The experimental group, however, scored much higher as a whole with all members answering above 85% of the items correctly. Specifically, the difference between the control and experimental groups were most marked for the females (33.34%) with the males in the experimental group scoring 16.27% more of the items correctly than the males in the control group.

**What is the most effective instructional methods in teaching sixth grade students spatial reasoning skills?**

A final assessment (Refer to Appendix H) was administered to both groups to gather data that may indicate if either 2-D sample sketching assignments or 3-D computer modeling software sample assignments provide a better learning experience, according to the test results, for 6th grade students in understanding spatial reasoning. The final assessment that was administered to both groups was identical in items, format, and concepts measured. The assessment consisted of fifteen items, each worth one point.

Table 4

*Final Spatial Reasoning Assessment Success Rate*

| Student Population | Control Group | Experimental Group | Difference of Experimental to Control Group |
|---|---|---|---|
| Female | 62.97% | 75.56% | +12.59% |
| Male | 68.89% | 78.15% | +9.26% |
| Total | 65.93% | 76.86% | +10.93% |

Overall, as seen in Table 4, the students in the experimental group scored above 75 percent with the highest score being associated with the males of that group (78.15%). Students in the control group, on the other hand, scored below 69 percent, with the females scoring 5.92% lower than the male students. However, the females demonstrated the largest performance differences as the students in the experimental group scored 12.59 percent higher than the female members of the control group. Overall, the control group scored approximately ten percent below the experimental group.

Table 5

*Final Spatial Reasoning Assessment Success Rates By Test Item*

| | Control Group | | | Experimental Group | | |
|---|---|---|---|---|---|---|
| Test Item | Male | Female | Class | Male | Female | Class |
| 1 | 75.00% | 77.78% | 76.39% | 77.78% | 83.34% | 80.56% |
| 2 | 91.67% | 100.00% | 95.83% | 83.34% | 100.00% | 91.67% |
| 3 | 50.00% | 66.67% | 58.36% | 61.12% | 50.00% | 55.56% |
| 4 | 75.00% | 77.78% | 76.39% | 88.89% | 100.00% | 94.45% |
| 5 | 66.67% | 44.45% | 55.56% | 72.22% | 66.67% | 69.45% |
| 6 | 50.00% | 77.78% | 63.89% | 66.67% | 66.67% | 66.67% |
| 7 | 58.34% | 55.56% | 56.95% | 88.89% | 83.34% | 86.12% |
| 8 | 66.67% | 55.56% | 61.12% | 83.34% | 83.34% | 83.34% |
| 9 | 75.00% | 44.45% | 59.73% | 66.67% | 83.34% | 75.01% |
| 10 | 50.00% | 55.56% | 52.78% | 77.78% | 50.00% | 63.89% |
| 11 | 83.34% | 55.56% | 69.45% | 77.78% | 66.67% | 72.23% |
| 12 | 50.00% | 22.22% | 36.11% | 72.22% | 33.34% | 52.78% |
| 13 | 91.67% | 88.89% | 90.28% | 94.45% | 100.00% | 97.23% |
| 14 | 83.34% | 66.67% | 75.01% | 83.34% | 100.00% | 91.67% |
| 15 | 66.67% | 55.56% | 61.12% | 77.78% | 66.67% | 72.23% |
| Total Ave. | 68.89% | 62.97% | 65.93% | 78.15% | 75.56% | 76.86% |

Test items 1-9 measured students' mental rotation and visual perception/visualization abilities. Regarding items 1, 2, 3 and 6, both groups achieved results within 5 percentage points of one another. However, it is noteworthy that the control group scored slightly higher on items 2 and 3, the only two items on the entire test on which the control group scored higher. On item 3, which assesses visual perception by asking the students to examine two views of the object to count its parts, the experimental group achieved its lowest success rate at 55.56%. This was over 11 points less than the next lowest mental rotation and visual perception score. The control group scored similarly low on item 3 at 58.36%.

On item 7, which also required mental rotation and visualization skills, the control group had a 29.17% lower success rate than the experimental group. This result could support the idea that manipulating virtual objects using 3-D computer software may enhance spatial reasoning ability.

The experimental group achieved a consistently higher success rate on items 10-15, which measured students' orthographic projection abilities. Specifically, the largest difference measured concerned item 12 where the experimental group scored 16.67 percent higher than the control group.

Only one item stands out as having a dramatically different result by gender. The female students in both groups had lower success rate with orthographic test item 12. Females in the control group scored 27.78 percentage points lower than their male counterparts, while females in the experimental group scored 38.88 percentage points lower than their male counterparts. This appears to be an isolated incident.

# Chapter V: Discussion

The purpose of this study was to investigate how effectively current traditional orthographic projection activities teach spatial reasoning concepts at the 6$^{th}$ grade level at Greendale Middle School. This study also investigated how effective three-dimensional computer modeling software methods teach spatial reasoning concepts. More specifically, the goal was to determine which is the more effective instructional method in teaching spatial reasoning concepts. The following summary, conclusions, and recommendations relate to the findings of student learning of this study. The population of this study was sixth grade students at Greendale Middle School. The sample consisted of two Greendale Middle School sixth Grade fourth quarter classes, or 25% of the sixth grade student population. The treatment of this case study included an introductory lesson about a few basic spatial reasoning/orthographic projection concepts. Then one class, the control group, participated in a series of 2-D isometric sketching activities. The other class, the experimental group, participated in a series of 3-D computer modeling software assignments. Lastly, both groups were given a final assessment (Refer to Appendix J) that was identical in items, format, and concepts measured. The assessment consisted of 15 items worth one point each.

## Limitations

The main limitation of this study in terms of being able to apply its findings more widely to other districts and classrooms is the relatively small number of students participating in the study, as well as the unique considerations of a suburban classroom.

Also it should be considered that the utilization of the two experimental groups occurring during different times of the day may affect student performance. The time of day when the experiment is administered was taken into account to select the two classes participating in the study. Klein

(2004) indicated that there is a significant decline in student achievement after the mid-to-late morning recess as well as during the early afternoon hours. Student achievement levels vary significantly throughout the hours of the school day (Klein, 2004), which made it important to conduct this experiment with two classes at a close time proximity. Two classes that were directly next to each other ($2^{nd}$ & $3^{rd}$ hours) during the school day were chosen because studies show that middle school student achievement is most successful during the mid-morning (10:00) time frame, prior to a break or recess (Klein, 2004).

**Conclusions**

The findings of this study were consistent with research articles provided in the Chapter 2 literature review that promote the use of computer software to help students learn spatial reasoning concepts. Specifically:

a. Students at the $6^{th}$ grade level often have great difficulty grasping spatial reasoning concepts when deciphering the information from 2-D isometric examples. Research tells us that students learn more from tools that they are accustomed to using, such as computers (Willis, 2006). Using isometric models as the primary teaching sample seem to be very ineffective regarding student understanding, yet it is common that textbooks and curriculum guides support the use of isometric models as the primary educational model in the directed curriculum (Wright, 2004).

b. The use of 3-D computer models to examine objects in order to sketch orthographic views and identify view rotations provided more overall success in this study, as indicated by the students' assessment results. The experimental group of students who worked with the 3-D modeling software scored approximately ten percent higher overall on the final assessment than the control group who worked without computer assistance.

c. The experimental group also had the most success completing the orthographic projection sketching assignments. The results indicated in the activity sheets show that students identify the views of an object more effectively when investigating the object using the 3-D modeling software. This is consistent with the Constructivist theory underlying this study, supporting the concept that 3-D modeling software enhances student learning because today's students have a large amount of personal experience with computer and electronic technology in general. By using the 3-D modeling software, this allowed students to attach personal meaning to their new knowledge.

d. The instructional methods for orthographic projection can be quite complex as a method to teach spatial reasoning concepts. Teachers commonly introduce these concepts with some form of a 2-D isometric sample. This often seems to create more confusion in the minds of sixth grade students. Isometric samples do have their place in spatial reasoning conceptual teaching methods, however they should not be the primary method of instruction for teaching these concepts.

e. When compared to the students who completed the spatial reasoning activities by only examining a 2-D isometric sample of an object, students were more successful in correctly answering items designed to assess spatial reasoning abilities when using 3-D computer modeling software to examine object samples.

**Recommendations**

The purpose of this study was to examine the most efficient way to teach the concepts of spatial reasoning to the sixth grade students enrolled in the subject of technology education at Greendale Middle School. More specifically this study looked at two possible methods of instruction: isometric models and 3-D computer models.

In consideration of the findings of this study, the following suggestions are proposed:

a. Continue to utilize isometric samples in the teaching of spatial reasoning, but not in isolation. Isometric views are currently used in the instructions of model building kits, and other types of instructional media. Isometric views are still utilized in most engineering designs so students will need to be taught the concepts of isometric views. A spatial skills course offered at Michigan Tech promotes a curriculum where students are assigned 2-D drawing activities for the first part of a lesson and then assigned 3-D computer software modeling and visualization activities to develop spatial reasoning skills. One activity consisted of rotating computer models to help understand and discuss the operations of object view transformation (Sorby, 2007). These course objectives should be utilized, with modifications, at the middle school grade levels. Students are very capable of object manipulation and transformation on the computer. When students finally get to the culminating activity of designing their project by using 3-D computer modeling software, they embrace the process more completely.

b. As this study showed, most sixth grade students are proficient with basic computer use and can examine 3-D computer models with ease. If educators have access to computers in their classroom, free software is available on-line, such as the Google Sketch-Up online design program. Students can create and investigate 3-D objects, which may spark their interest to learn spatial reasoning concepts.

c. Teachers should utilize 3-D computer models in early instructional lessons when teaching the concepts of spatial reasoning. When students actually manipulate computer-simulated models, the top, front, and right sides of the object become very apparent (Golon, 2008).

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APPENDIX A

# Group A Lesson Plan

## Spatial Reasoning/Orthographic Projection Design Introduction Lesson Plan

**Length of Lesson:** 4-5 (45 min.) class periods

**Subject Area:** Technology Education

## Objective

Students will:

- Participate in learning activities to assess their current understanding of the basic spatial reasoning concepts.
- Use isometric drawings examples to complete orthographic projection drawings in order to identify proper views of orthographic projection drawings.
- Complete a final assessment that indicates their ability to properly identify basic spatial reasoning concepts after conducting a series of orthographic projection assignments through traditional isometric exercises.

## Materials

- Pencils
- Object Rotation Recognition Sheet
- 2-D Orthographic Sketching Lab Sheet
- Orthographic Projection Exercise Sheet
- Final Orthographic Projection/Spatial Reasoning Assessment

## Procedure

### Day 1

1. Introduce spatial reasoning concepts by having students complete Object Rotation Recognition Sheet.
2. Show the class a projection of an isometric drawing of an object that could be manufactured and explain why there is a need for designs, or drawings, to be made to communicate the details to construct the object or part.
3. Draw an orthographic projection of the object while explaining the view names, arrangement, and alignment of the object.
4. Have the students draw the exact example that you had drawn of the sample object as you continue talking about the characteristics of orthographic projection.

### Day 2

5. Review object rotation and orthographic projection concepts covered in previous class.
6. Hand out the 2-D Orthographic Sketch Lab Sheet and allow students time to complete.
7. Provide examples of spatial reasoning puzzles and ask the students to solve as a large group.

### Day 3

8. Review spatial reasoning and orthographic projection concepts with the class.
9. Hand out the Final Orthographic Projection Exercise Sheet and allow time to complete.

### Day 4

10. Administer Final Orthographic Projection/Spatial Reasoning Assessment.

## Evaluation

The students will be evaluated using the following criteria:

- The assignment sheets will be graded with 1 point awarded for each correct entry.
- The test will be graded using a 15-point scale, 1 point awarded for each correct entry

APPENDIX B

# Group B Lesson Plan

# Orthographic Projection Design Introduction Lesson Plan

**Length of Lesson:** 4-5 (45 min.) class periods

**Subject Area:** Technology Education

## Objectives

Students will:

- Participate in learning activities to assess their current understanding of the basic spatial reasoning concepts.
- Use three dimensional computer models to complete orthographic projection drawings in order to identify proper views of orthographic projection drawings.
- Complete a final assessment that indicates their ability to properly identify basic spatial reasoning concepts after conducting a series of orthographic projection assignments through the use of three dimensional computer model exercises.

## Materials

- Computers with modeling software installed.
- Pencils
- Object Rotation Recognition Sheet
- 3-D Software Orthographic Sketching Lab Sheet
- 3-D Software Orthographic Drawing Assignment Sheet
- Final Orthographic Projection/Spatial Reasoning Assessment

## Procedure

### Day 1

1. Introduce spatial reasoning concepts by having students complete Object Rotation Recognition Sheet.
2. Show the class a projection of a 3-D computer model of an object that could be manufactured and explain why there is a need for designs, or drawings, to be made to communicate the details to construct the object or part.
3. Draw an orthographic projection of the object while explaining the view names, arrangement, and alignment of the object.

4. Have the students draw the exact example that you had drawn of the sample object as you continue talking about the characteristics of orthographic projection

**Day 2**

5. Review object rotation and orthographic projection concepts covered in the previous class.
6. Hand out the 3-D Software Orthographic Sketch Lab Sheet and allow students time to complete.
7. Provide examples of spatial perception computer activities and ask the students to solve as a large group.

**Day 3**

8. Review spatial reasoning and orthographic projection concepts with the class.
9. Hand out the final 3-D Software Orthographic Drawing Assignment Sheet and allow time to complete.

**Day 4**

10. Administer Final Orthographic Projection/Spatial Reasoning Assessment.

**Evaluation**

The students will be evaluated using the following criteria:

- The assignment sheets will be graded with 1 point awarded for each correct entry.
- The test will be graded using a 15-point scale, 1 point awarded for each correct entry

APPENDIX C

Name ____________________

Object Rotation Recognition Sheet    Hour___________

**Here is a brain exercise to stimulate your object rotation skills.**

- The top shape is your model.
- Among the 3 shapes below the model, only one matches the model. To figure out which one does you will probably have to move the shapes around in your head.
- Move the shapes from left to right or right to left, but DO NOT FLIP them around.
- Circle the correct rotated shape.

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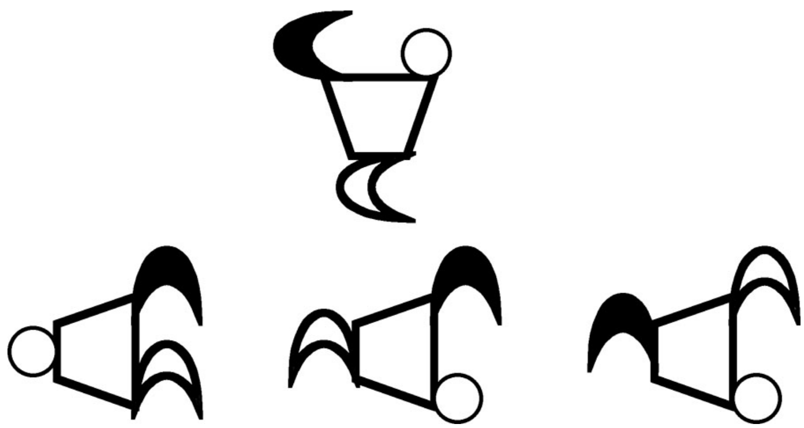

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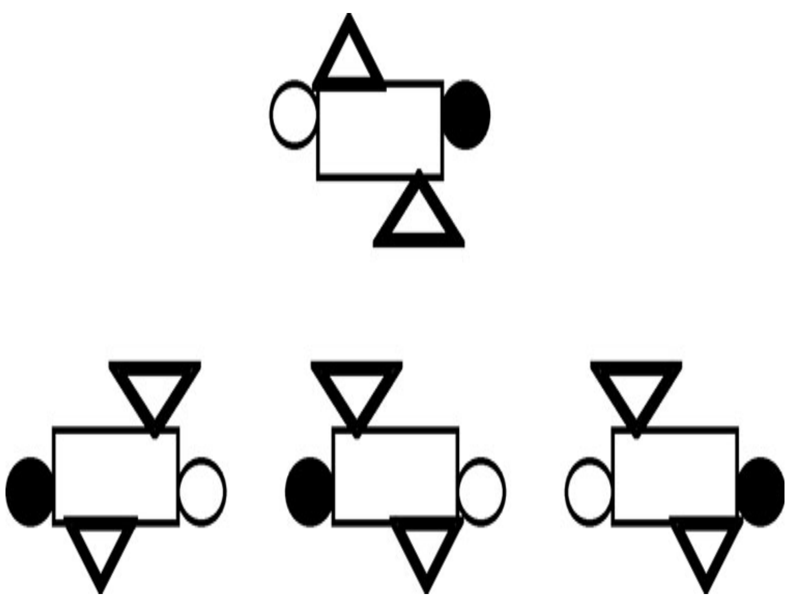

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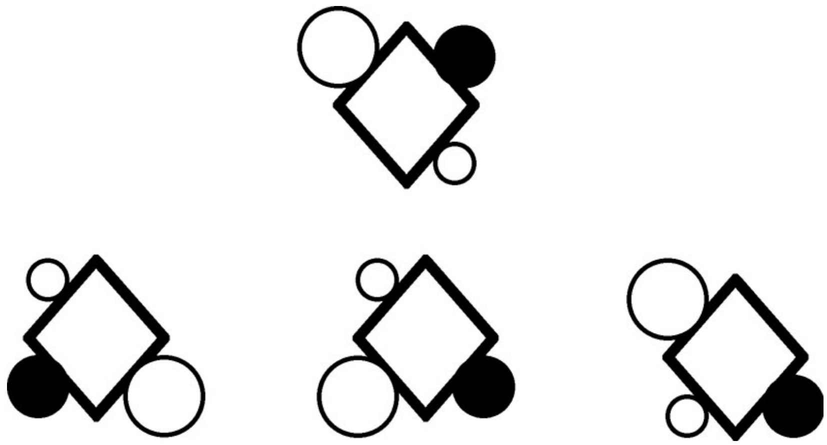


In the space provided below, please take some time to create your own object rotation puzzle and have a classmate next to you solve it.

APPENDIX D

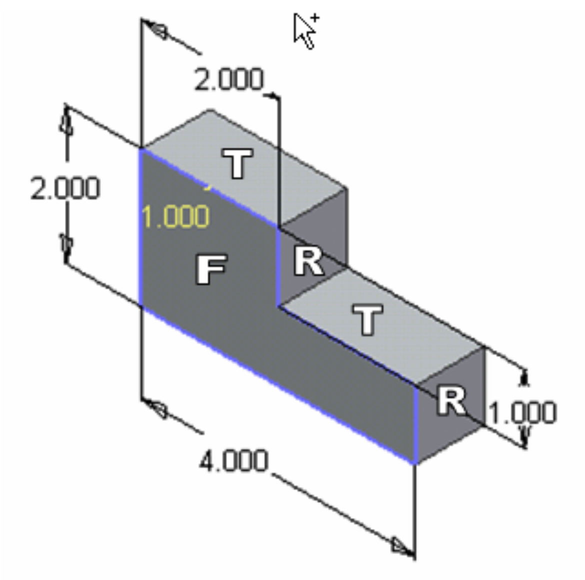
Name ______________________

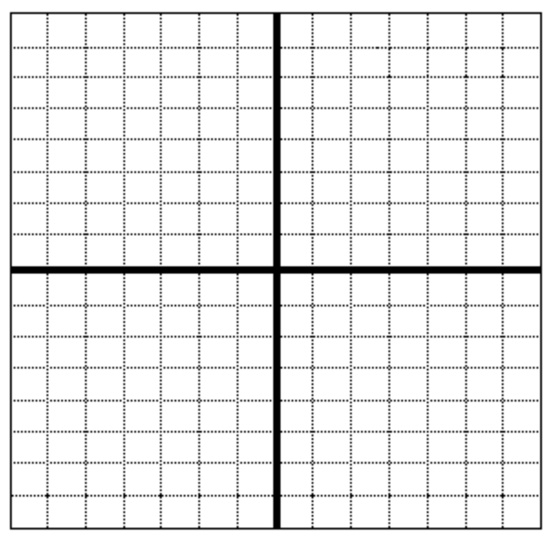
Hour______________

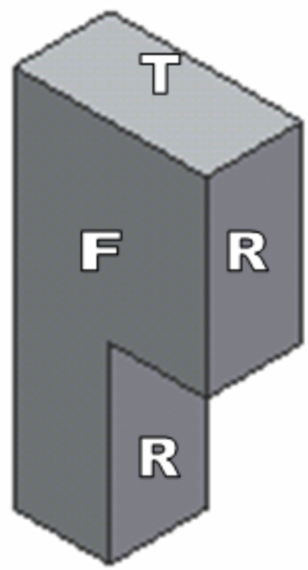
**2-D Orthographic Sketching Lab Sheet**

In this part of the activity, you will use the same block to draw at least three different drawings. In each drawing, the block is turned to a different position. If time permits, try completing all drawings.

1. In each position shown, draw the top, front, and right side views of the block.
2. The dimensions of the block are given in **Figure 1** and are to be used for all the drawings of the block.
3. Each small square represents **one inch**.
4. **Notice** that the placement of the block in a drawing, the fit in the drawing space may be better than in other views. You will also notice that each drawing may have a different number of hidden lines

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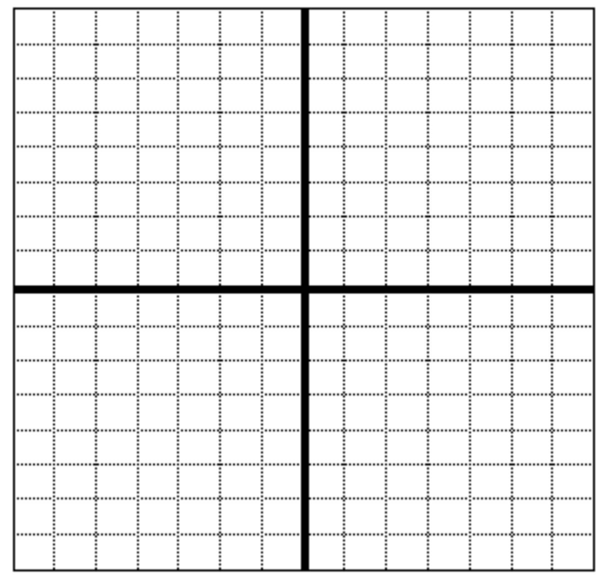

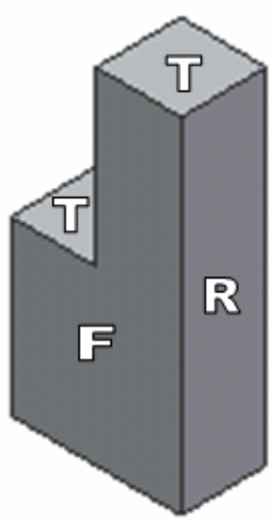
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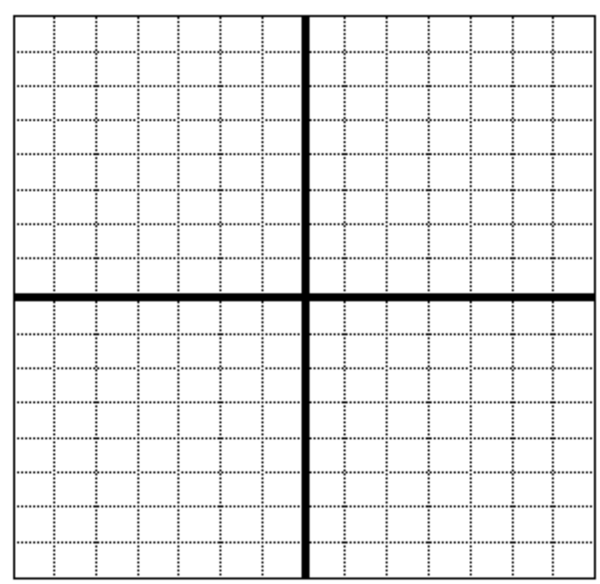

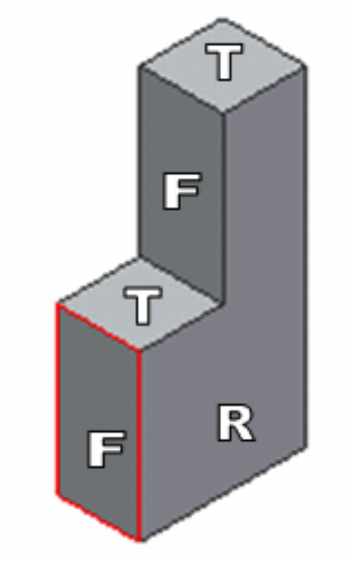
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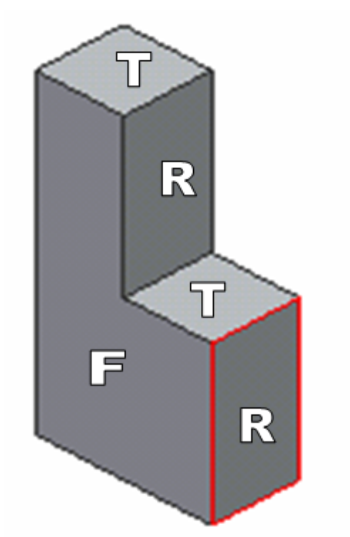
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APPENDIX E

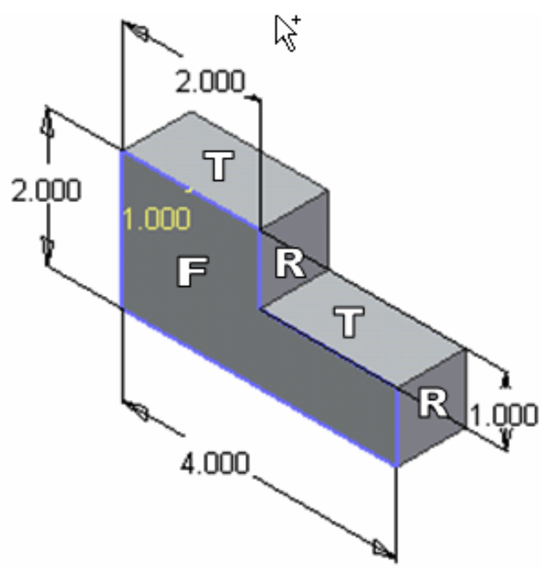
Name ________________________

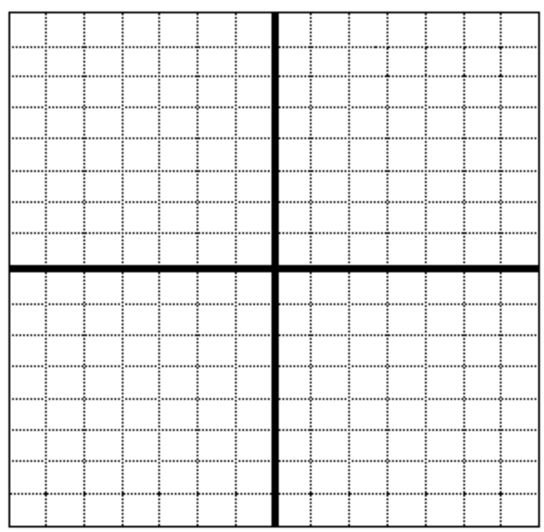
Hour________________

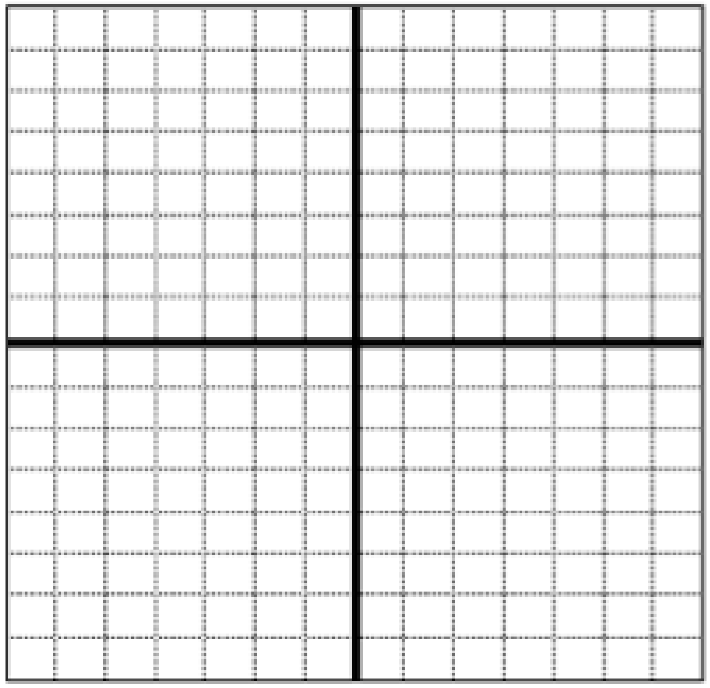
**3-D Software Orthographic Sketching Lab**

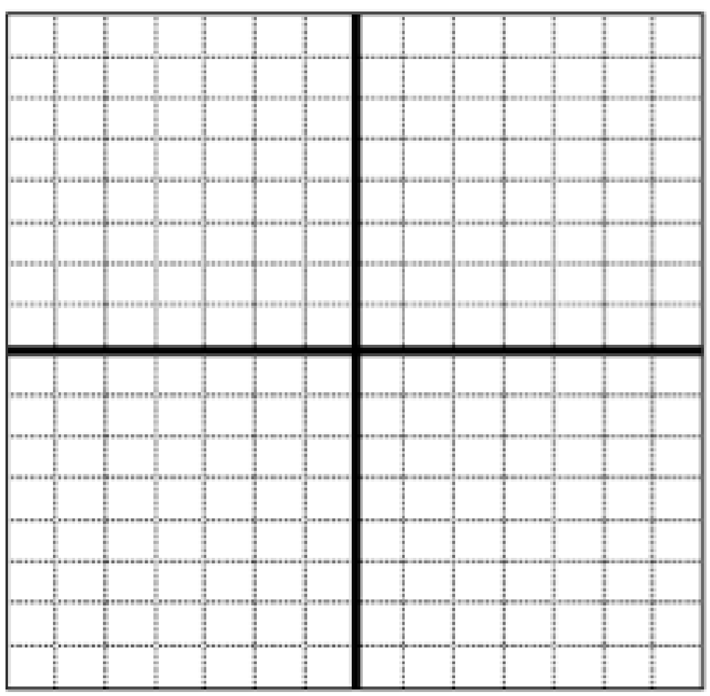
In this part of the activity, you will use the same computer generated 3- D block to draw at least three different drawings. In each drawing you will draw the block in a different position. If time permits, try completing all drawings.

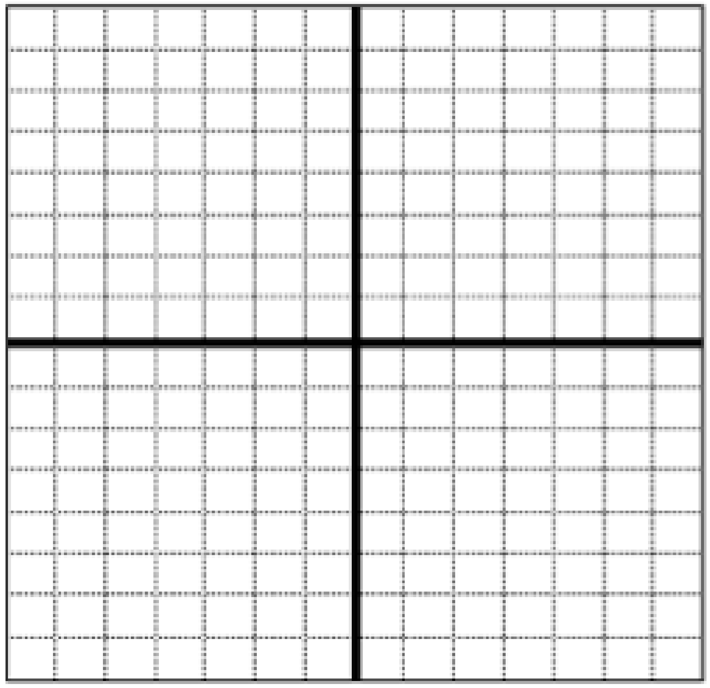
1. In each position shown, draw the top, front, and right side views of the block.
2. The dimensions of the block are given in **Figure 1** and are to be used for all the drawings of the block.
3. Each small square represents **one inch**.
4. **Notice** that when you rotate the placement of the block in a drawing, the fit in the drawing space may be better than in other views. You will also notice that each drawing may have a different number of hidden lines

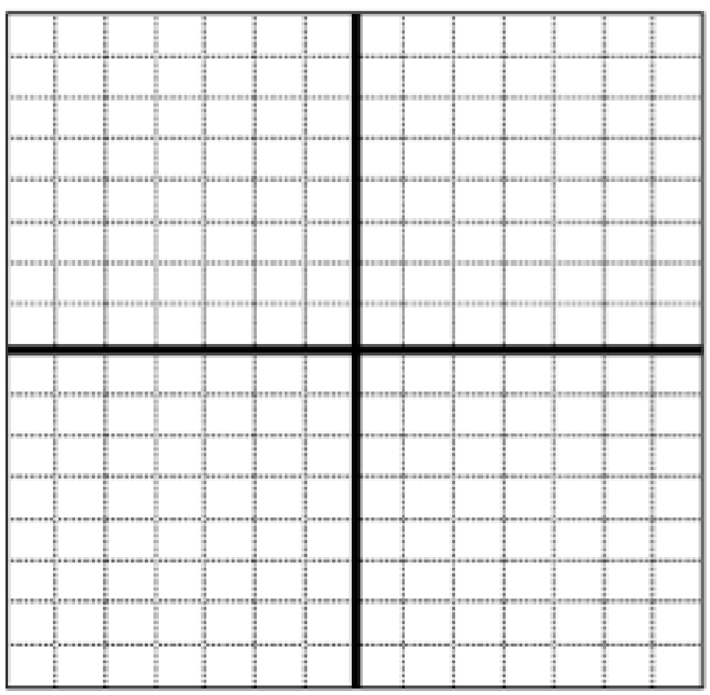










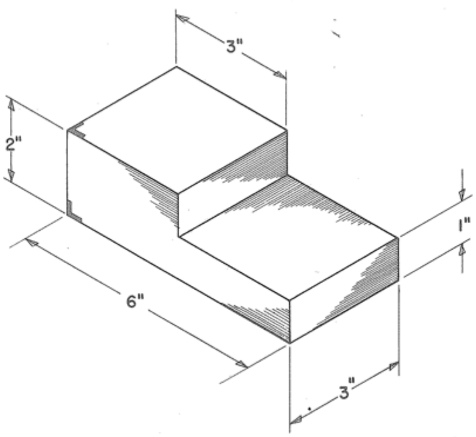
APPENDIX F

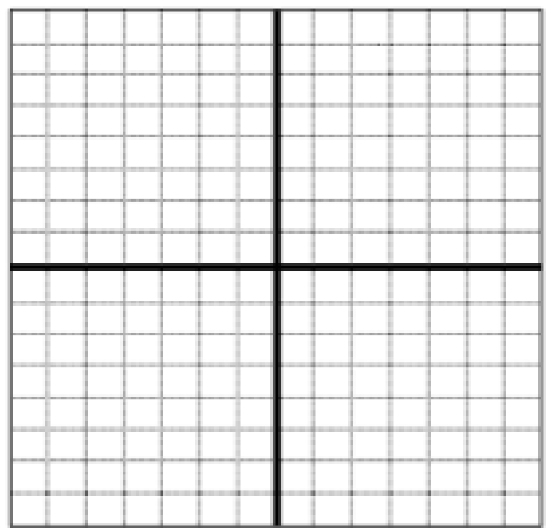
Name ___________________________

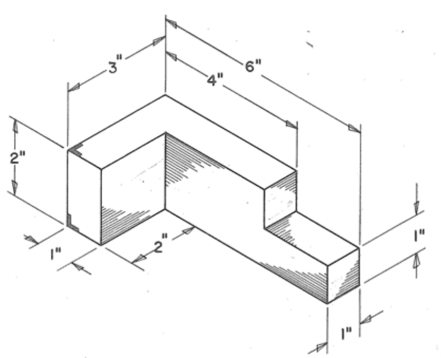
Hour ____________

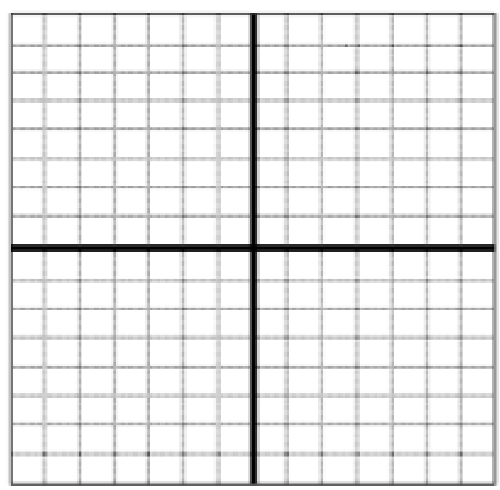
# Orthographic Projection Exercise Sheet

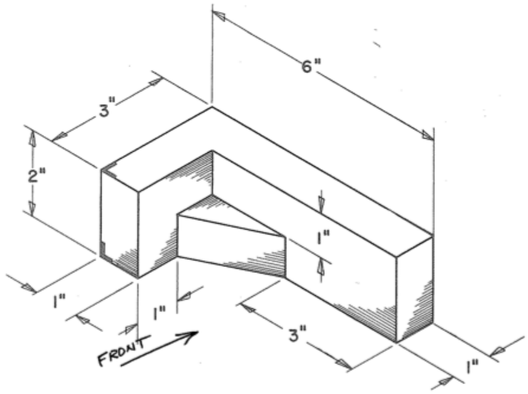
Draw the orthographic projections of each isometric shape.
Do not dimension the drawing.



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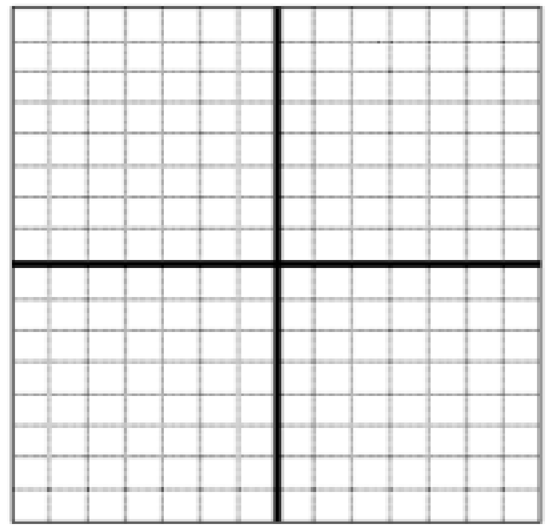
1"
FRONT



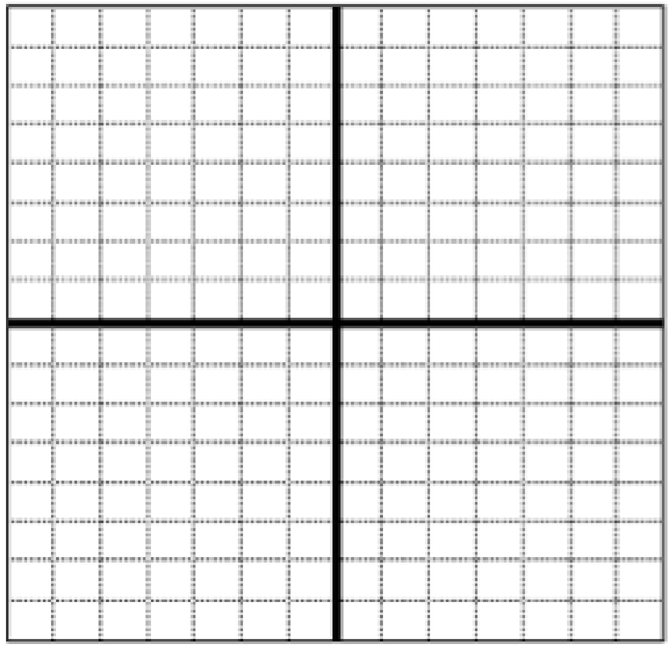
APPENDIX G

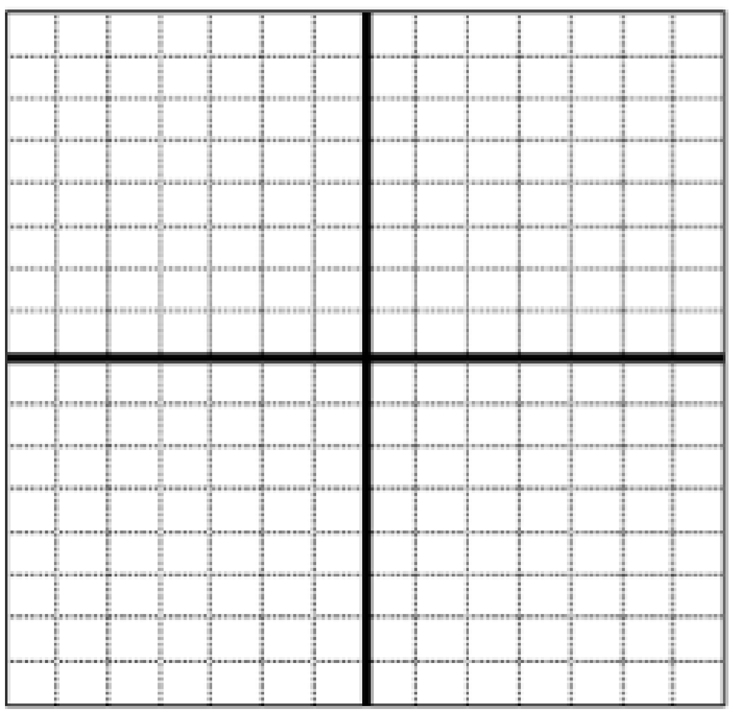
Name ________________________

Hour________________

**3-D Software Orthographic Drawing Assignment Sheet**

In this activity you will use the computer software generated 3- D blocks provided to draw three different orthographic projections.



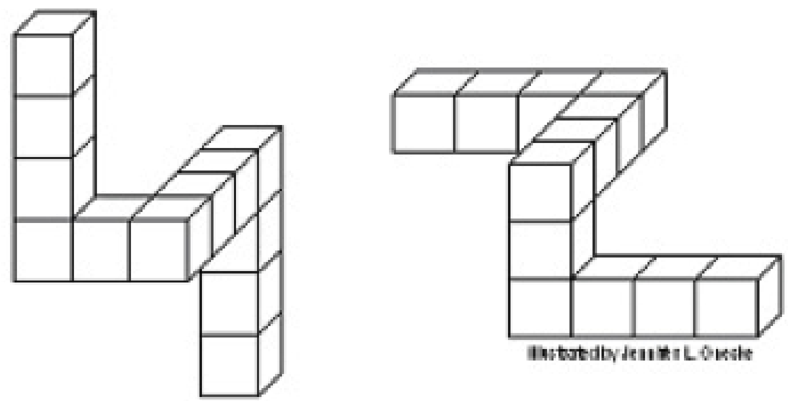


APPENDIX H

# Final Orthographic Projection/Spatial Reasoning Assessment

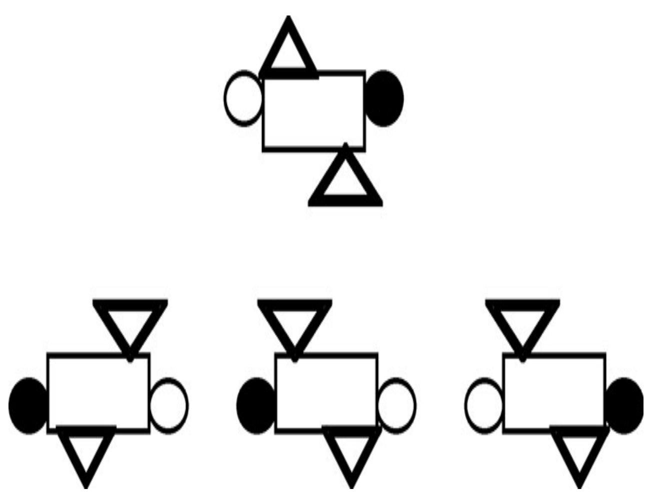
**1.** Are these two block shapes below the same or different? Circle one.

Same Different

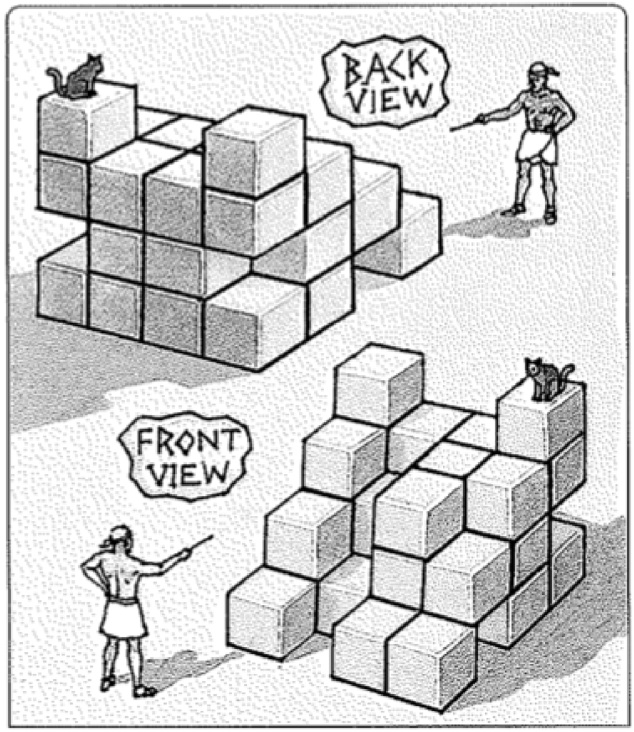


**2. Here is a brain exercise to stimulate your object rotation skills.**

- The top shape is your model.
- Among the 3 shapes below the model, only one matches the model. To figure out which one does you will probably have to move the shapes around in your head.
- Move the shapes from left to right or right to left, but DO NOT FLIP them around.
- Circle the correct rotated shape.



**3.**



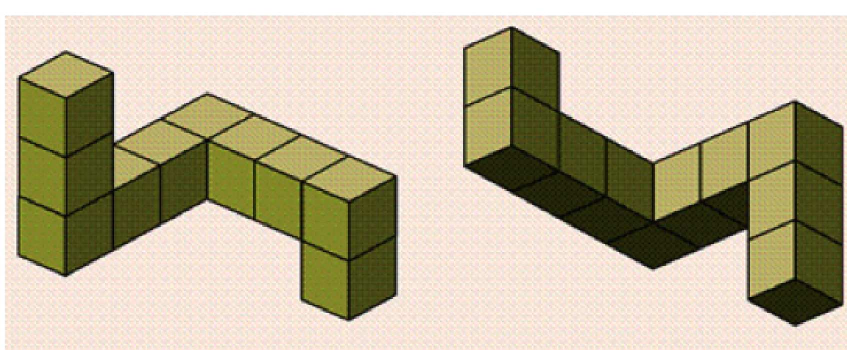

**Counting Cubes...**

The stone cutter and his cat are trying to count the number of cubes that have already been placed in this monument. Can you determine the total number of cubes contained in this structure, based on seeing these front and back views and armed with the knowledge that it is not in any way hollow?

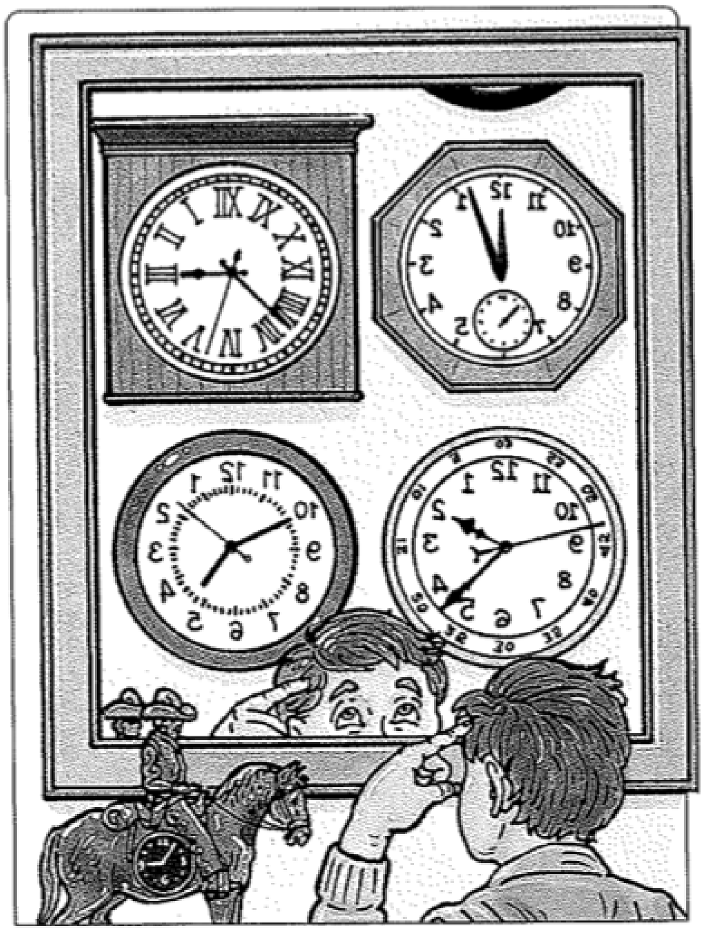
Number of Cubes __________

**4.** Are these two block shapes below the same or different? Circle one.

Same Different



**5.**



**Time Check…**

Looking into a large mirror, Jimmy sees the reflections of four clocks. If each clock chimes every hour, which one will be the next to chime?

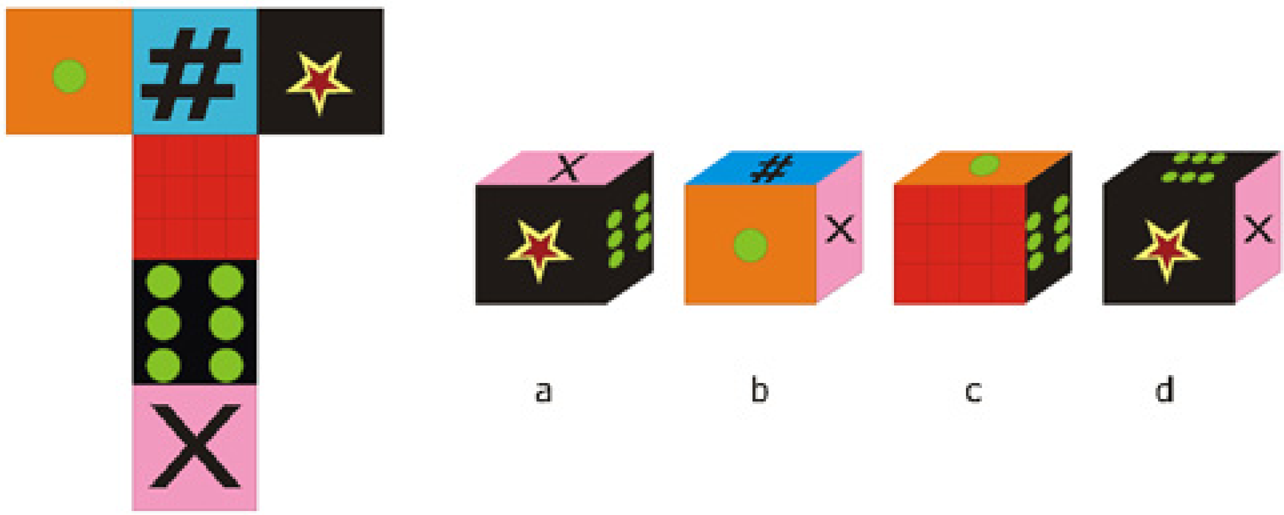
Draw a dark arrow to the correct clock.

When the Bambeani triplets were born they each received an identical jumbo birthing block. At age 65, they still have their blocks and if asked, will proudly show them to you. Can you tell which shape is on the bottom of each block?

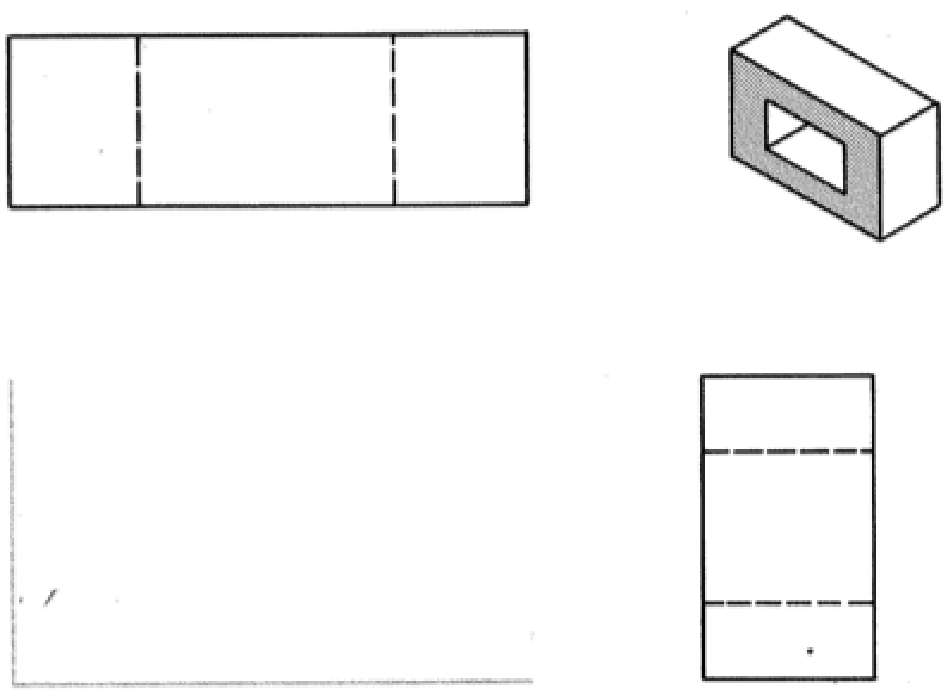
Circle the correct shape for each block.

| | | | | | | |
|---|---|---|---|---|---|---|
| **6.** | **Left** - | Square | Circle | Star | Diamond | Clover |
| **7.** | **Center** - | Square | Circle | Star | Diamond | Clover |
| **8.** | **Right** - | Square | Circle | Star | Diamond | Clover |

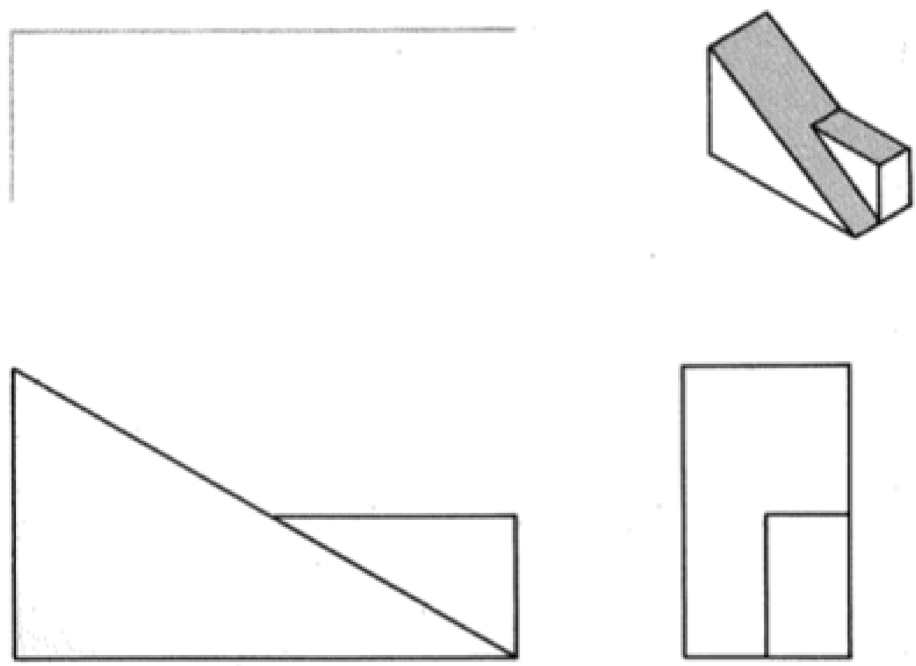
**9.** Circle the correct letter of the cube that matches the unfolded T shape on the left.



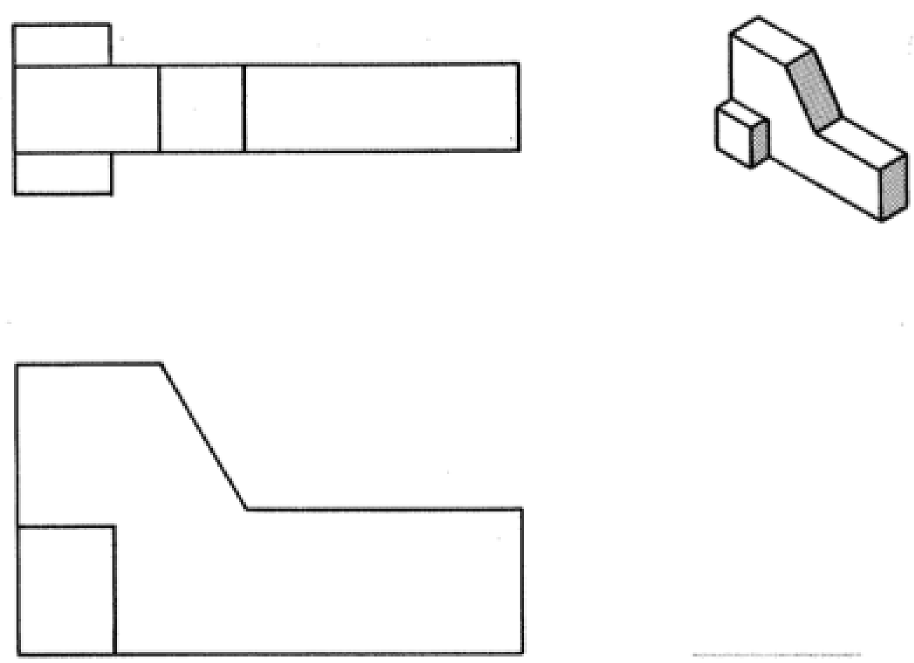

**10.** Draw the missing view.



**11.** Draw the missing view.

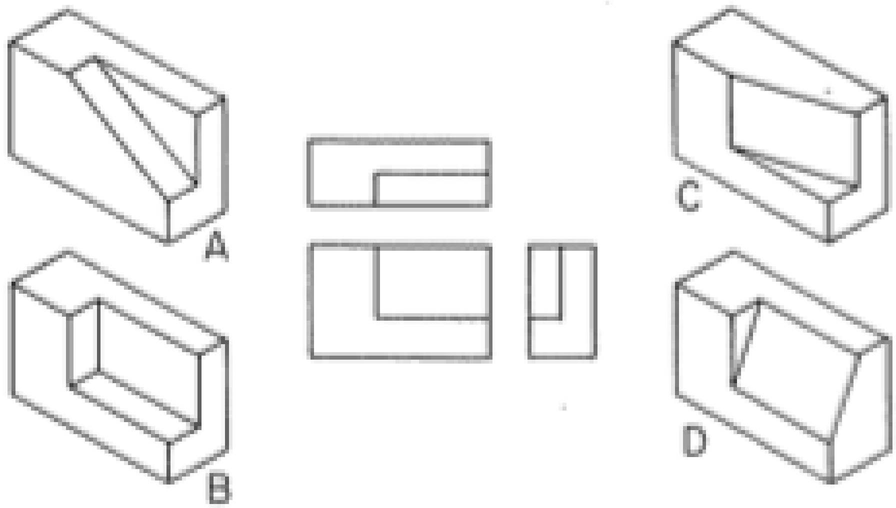


**12.** Draw the missing view.

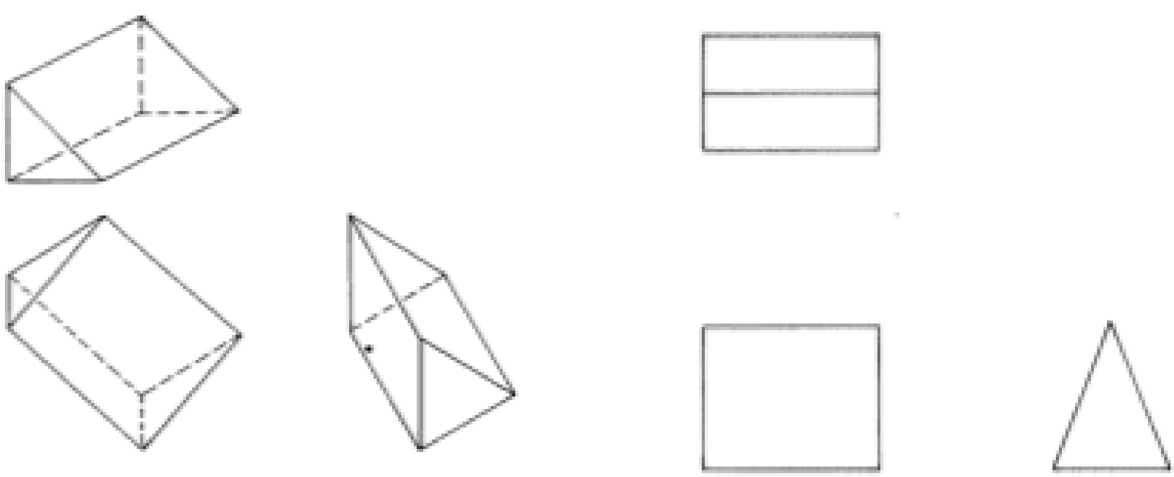


**13.** Circle the correct letter of the isometric object that matches the orthographic projection.

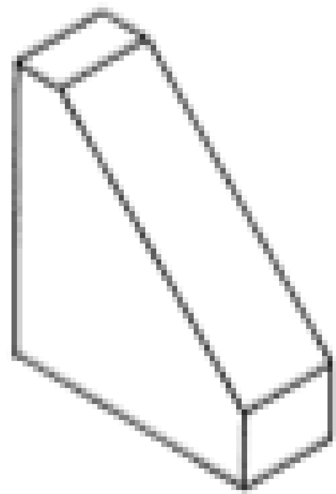
A B C D

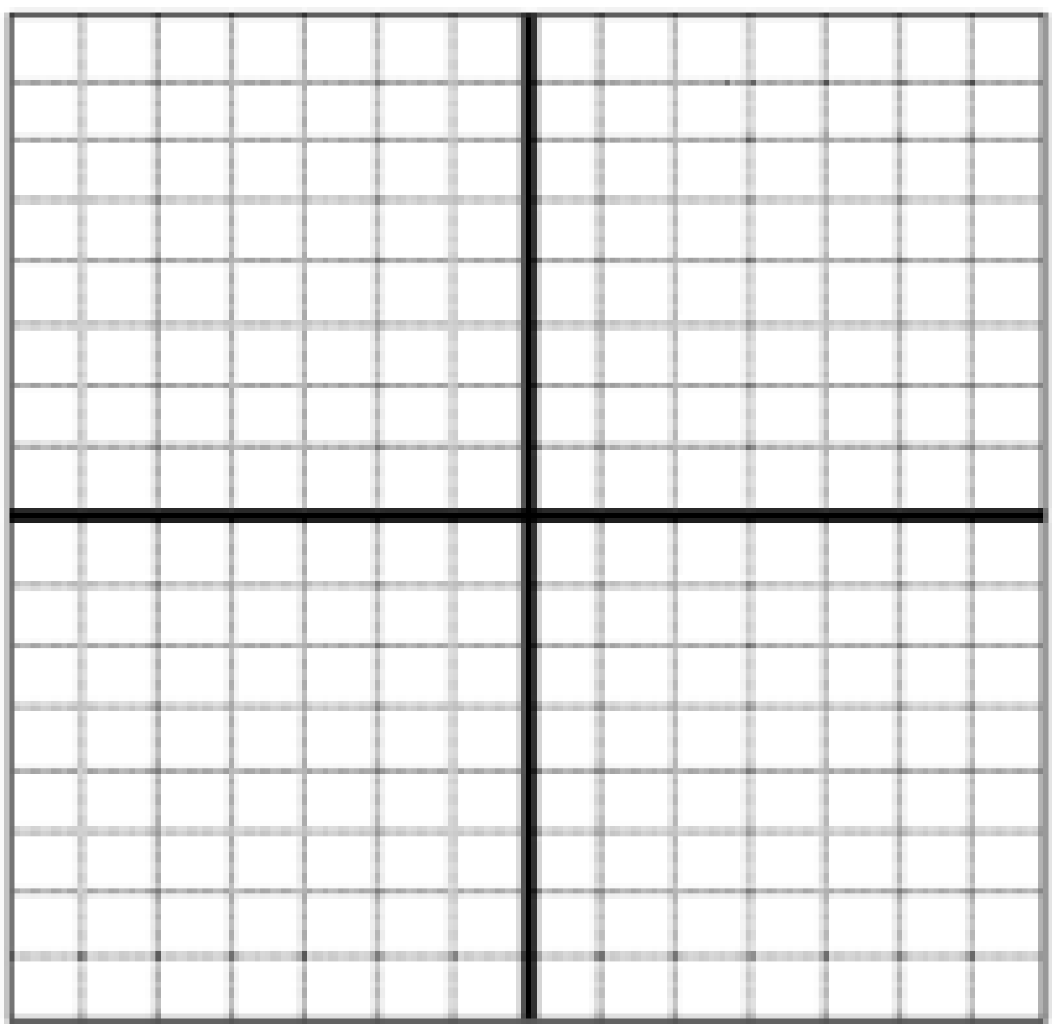



**14.** Circle the rotated object in the left set that is shown in the orthographic projection on the right.



**15.** Draw the orthographic projection of the object below.





APPENDIX I

**Consent to Participate In UW-Stout Approved Research Title**: An Analysis of the Effectiveness of Orthographic Projection Activities in Teaching Spatial Reasoning Concepts to Sixth Grade Students at Greendale Middle School.

**Investigator:**
Robert Ligocki (414) 421-1779 robert.ligocki@greendale.k12.wi.us

**Research Sponsor:**
David Stricker
strickerd@uwstout.edu

**Description:**
The population of this study is all sixth grade students at Greendale Middle School. The sample will consist of two Greendale Middle School sixth Grade third or fourth quarter classes. The study will begin with introductory learning activities to examine prior student knowledge about spatial reasoning and the effectivness of orthographic projection acivities on learning of spatial reasoning. Three sample shapes will be used in the two methods of instruction. After the introductory learning activities, students will be assigned specific examples of shapes to sketch in an orthographic projection format. One group will examine two-dimensional drawings of a shape to draw in the proper orthographic projection format. Another group will examine a three-dimensional computer model of a shape to draw in the proper orthographic projection format. At the end of the unit, the students will participate in a final test that will consist of view identification to communicate the knowledge of spatial reasoning concepts. These drawings, along with data collected from the exam, will inform the study.

**Risks and Benefits:**
Educators who teach middle school technology education or engineering design concepts may appreciate the approach used to assignments and practices that this study utilizes relative to the spatial reasoning principles.

**Special Populations:**
Sixth Grade Greendale Middle School students who are involved in spatial reasoning lessons as part of their required curriculum will be the participants in this research.

**Time Commitment and Payment:**
The student time commitment necessary to complete this research will be five class periods. This will be completed as part of the required Greendale Middle School curriculum.

**Confidentiality:**
The student's names will not be included on any research documents or the study. Students will not be identified from any of this research information.

**Right to Withdraw:**
The students' participation in this study is required as a typical curricular assignment. However, students may wish for their work not to be used as part of the study.

**IRB Approval:**
This study has been reviewed and approved by The University of Wisconsin-Stout's Institutional Review Board (IRB). The IRB has determined that this study meets the ethical obligations required by federal law and University policies. If you have questions or concerns regarding this study please contact the Investigator or Advisor. If you have any questions, concerns, or reports regarding your rights as a research subject, please contact the IRB Administrator.

**Investigator:**
Robert Ligocki 414-421-1779
robert.ligocki@greendale.k12.wi.us

**Advisor:**
David Stricker 715-232-2757
strickerd@uwstout.edu

**IRB Administrator**
Sue Foxwell, Director,
Research Services 152 Vocational Rehabilitation Bldg.
UW-Stout Menomonie, WI 54751 715-232-2477
foxwells@uwstout.edu

**Statement of Consent:**
By signing this consent form you agree to participate in the project entitled, "An Analysis of the Effectiveness of Orthographic Projection Activities in Teaching Spatial Reasoning Concepts to Sixth Grade Students at Greendale Middle School."

Student Name ___________________________________________________

Student Signature: ..........................................................................................
Date_______________

Parent Name ___________________________________________________

Signature of parent or guardian: ..........................................................................
Date______________