Enhancing Spatial Visualization Skills in Engineering Drawing Course

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Abstract

Strong spatial visualization skills are important to an engineer's ability to create and interpret technical drawings, which is critical in thinking, modeling, and problem solving processes. The ability to visualize in three dimensions is a cognitive skill that is linked to success in engineering. Spatial visualization skill and its correlation with students' success has received much attention in technical education. The ability to understand important topics in engineering drawing such as orthographic projection, isometric drawing, hidden views, and sectional views is very critical as it represents the fundamentals of engineering drawing education. However, research shows that some learners with poor spatial ability had trouble understanding basic fundamental concepts of engineering drawing. This study investigates the correlation between spatial visualization ability and academic success in a Technical Drawing course which has three sections (i) hand drafting, (ii) two dimensional (2D) CAD drawing, and (iii) three dimensional (3D) CAD drawing. Students were pre- and post-tested using a standard mental rotation test to gauge spatial visualization ability and results are discussed for three sections of this course.

1. Introduction

All engineering technology students are required to take the engineering drawing course in their freshmen year. It is designed to teach principals of drawing and 2D/3D CAD modelling techniques. Descriptive geometry is a part of this course and fundamental for each creative activity of prospective engineers. It provides object visualization, spatial cognition of problems, geometric reasoning, and graphic representation of ideas.

Traditionally engineering students are expected to read projection views of technical objects and visualize them or start with isometric view and create principle orthographic views. It is well known that students struggle in figuring out how to generate necessary projection views in order to solve the problem while transforming views between 2D and 3D views of objects [1,2].Over the past few decades, traditional manual drawing has been replaced by CAD software with graphic output including projection views are created automatically by software. People think CAD made traditional board drawing obsolete. This is a fact, but only students with profound understanding of geometry and spatial skills can make best the use of CAD systems and be an engineer with excellent design skills.

Students with good spatial ability did not have difficulties grasping concepts and can successfully solve engineering problems, whereas students who had not developed spatial ability had difficulties learning. It is reported by many researchers that the spatial ability cannot be taught but that the capacity is innate[3-6]. However opponents have argued that spatial aptitude can indeed be enhanced through carefully constructed exercises[7,8]. New studies show that these skills can be improved with practice[9-12] . Childhood activities involving art and sketch, playing video games, participating sport activities, and construction games or toys that give tactile experiences with concrete objects are also among the positive socio-cultural influences listed by researchers[13-15].

This study investigates the correlation between spatial visualization ability and academic success in a Technical Drawing course which has three sections (i) hand drafting, (ii) two dimensional (2D) CAD drawing, and (iii) three dimensional (3D) CAD drawing. Students were pre- and post-tested using a standard mental rotation test to gauge spatial visualization ability and also asked about their interest in video games. Results are discussed for three sections of this course.

2. Description of the Engineering Drawing Course

At the University of Pittsburgh at Johnstown, all engineering students are required to take ET0011, Engineering Drawing. This is typically taken during the freshmen year by students in all four majors - Civil, Electrical, Computer, and Mechanical Engineering Technology. The objectives of ET0011 include:
(1) Interpret and communicate with technical drawings and sketches,
(2) Use current computer aided graphics software,
(3) Understand and apply standard graphical principles.

These purposes recognize that in the field of engineering, much information is conveyed in graphical form, that successful design is often accomplished in a graphical environment, and that practical graphical skills are required for many entry-level engineering jobs.

The course content of ET0011 is delivered in three formats – hand drawing and sketching, 2-D CADD, and 3-D CADD. The class meets three times a week, twice in a computer lab and once in a classroom equipped with drawing boards. In the computer lab, AutoCAD is taught for the first half of the semester, and AutoDesk Inventor for the second half. In the classroom the main emphasis is on theory and problem-solving, and exercises are done in the form of sketches rather than mechanical drawing. Concepts covered in one format are often reinforced in another format. For example, students learn how to imagine and create sectional views in the classroom, and then create sectional views in Inventor.

Topics covered in ET0011 can be organized into three major categories as follows, in approximately sequential order within each category:

I. Visualization – developing a mental image of a part, and expressing it in various forms.
   a. Classroom – Basics of orthographic projection
   b. Classroom – Creating 3-D foam models of parts
   c. AutoCAD to solve orthographic projection problems
   d. Classroom – Basics of isometric drawings
   e. Classroom – Basics of auxiliary views
   f. Classroom – Basics of sectional views
   g. AutoCAD and Inventor to create auxiliary views
   h. Inventor to create sectional views
   i. Classroom – Exercises in descriptive geometry

II. Learning software.
   a. AutoCAD basics, then introducing new commands as needed each class session
   b. Learning by practice – using AutoCAD to solve visualization problems and create drawings
   c. Inventor basics, then introducing new commands as needed each class session
   d. Learning by practice – using Inventor for a 3-week project in assembly modeling
   e. Exposure to software capabilities – AutoCAD layout space, Inventor Frame Generator
   f. Application to design – AutoCAD design layout problem, Inventor creation of unique parts for the project

III. Drawing creation.
   a. AutoCAD – rules and guidelines for drawing and dimensioning formats and styles
   b. Inventor – dimension styles, practice making drawings
   c. Classroom – tolerances

The learning skills students need to apply vary significantly with topics. Learning software and drawing creation depend largely on memory, repetition, and paying attention to detail. On the other hand, visualization requires the ability to form a 3-D mental image of a part based on limited or incomplete information. For some students, this comes naturally and without much analysis. For others, the given information must be analyzed and synthesized in a logical manner. The drawing course at UPJ aims to provide students in the second group the instruction and opportunity to practice that process enough that it becomes easier over time.

3. Definition of spatial skills and success in engineering

There are five levels of understanding to geometric thought development which are defined by the van Hiele model that is known over 25 years in geometry education. [16] Levels of understanding are described as (i) Visualization: The student reasons about basic geometric concepts, such as simple shapes, primarily by means of visual consideration of the concept as a whole without explicit regard to properties of its components. (ii) Analysis: The student reasons about geometric concepts by means of an informal analysis of component parts and attributes. Necessary properties of the concept are established. (iii) Abstraction: The student logically orders the properties of concepts, forms abstract definitions, and can distinguish between the necessity and sufficiency of set of properties in determining a concept. (iv) Deduction: The student reasons formally within the context of a mathematical system, complete with undefined terms, axioms, an underlying logical system, definitions and theorems.(v) Rigor: The student can compare systems based on different axioms and can study various geometries in the absence of concrete models[17].

Spatial skill refers to a skill set consisting of mental rotation, spatial perception, and spatial visualization of objects or projections of them[18,19]. It is the ability to rapidly and accurately rotate two or three dimensional figures, to determine relations with respect to their orientations, and to visualize their image in mind[20].Some researchers investigated dynamic spatial reasoning and added it to this set [21].

It is accepted that the ability to spatially visualize an object is an important tool required of engineers in order to function effectively[22-25].

Traditionally engineering students are expected to read 2D projection views of technical objects and visualize them or start with isometric view and create principle orthographic views. Students tend to struggle in figuring out how to generate 3D objects or other necessary projection views in order to solve the problem while analyzing projection views in 2D. Over the past few decades, traditional manual drawing has been replaced by CAD software with graphic output including automatically generated projection views. People think CAD made traditional board drawing obsolete. This is a fact, but only students with profound understanding of geometry and spatial skills can make best the use of CAD systems and be an engineer with excellent design skills. Students with spatial skills can successfully solve engineering problems, but studies show that these skills can be improved with practice.

4. Enhancing spatial skills development

Spatial visualization and graphical representation skills are essential for engineering students to allow them to express ideas in the course of solving problems. Knowledge is not a copy of reality based on Piaget's theories[26]. "*To know an object is not simply to look at it and make a mental copy or image of it. To know is to modify, to transform the object, and to understand the process of this transformation, and as a consequence to understand the way the object is constructed*"[27]. Piaget claimed "*The construction of space begins on the perceptual level and continues on the representational one*"[28]. Representations in education are commonly divided into internal and external representations. External representations happen outside the mind and can serve to communicate organized thoughts for ourselves or others, and include such things as graphs, text, diagrams, drawings, equations, models and prototypes. The understanding of concepts can be improved through the connections made between the student's internal representations and the external representations in a learning environment. Representations, both internal and external, work up together and are building blocks of constructivist learning[29]. Different students with different learning needs should use different representations in classroom. Therefore, different approaches are used to improve the spatial visualization skills. The simplest and oldest of these approaches are concrete representations such as wooden blocks to be depicted graphically by the student that can be observed, touched, and measured (Figure 1). During this activity, they observe the model inside the glass box and generate three principle orthographic projection views. Glass box is used to show the projection views of an object. This is very effective for tactile learners who learn by touching and manipulating objects[30,31].

Figure 1 Glass box approach

Another approach is creating simple foam models. Students build foam models starting from isometric sketches during the class in ET0011 (Figure 2).

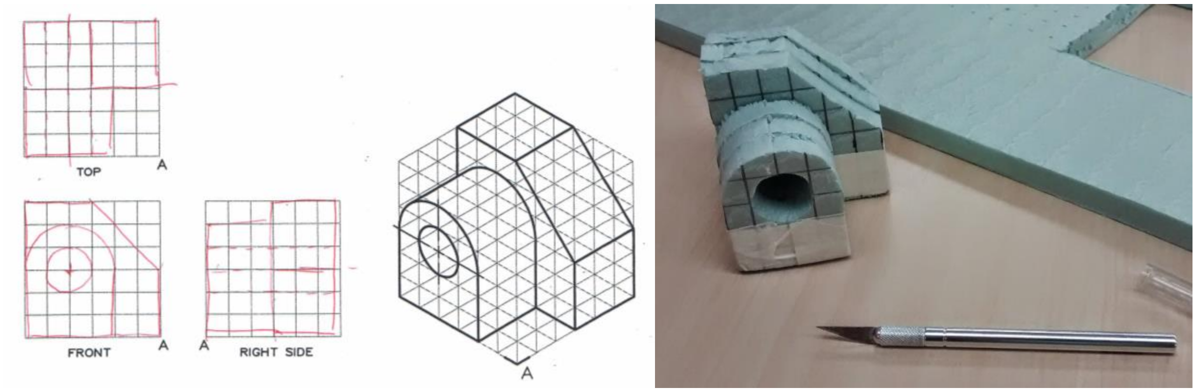

Figure 2 Foam model built by student

Dynamic representations of three dimensional models on a computer screen are other forms of representation that can help students see the object from different perspectives (Figure 3). Inventor CAD system is used to visualize and inspect the geometry from different point of views.

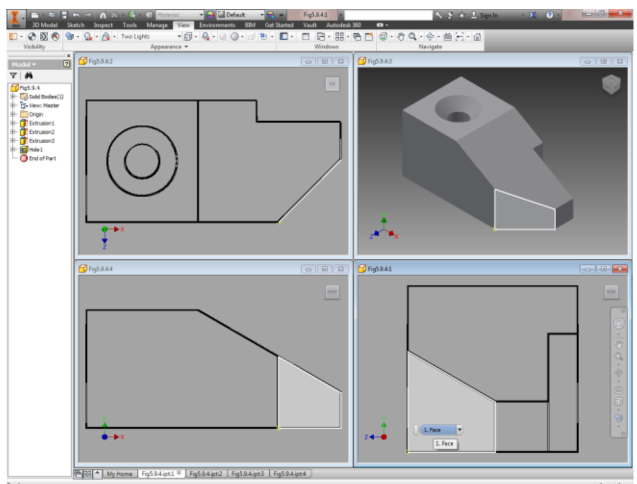

Figure 3 Projection views in CAD

These external representations may enhance students' comprehension of a concept. However, it is important to see that students do not necessarily have the skill set to synthesize an external representation provided by a peer or instructor without creating the ability to internalize.
The cognition of the student can be positively impacted through the connections made between the student's internal representations and the external representations in a learning environment.

Especially for tactile learners glass box can be used to make these connections. Descriptive geometry concepts are easily comprehended by students with hands-on class activities using wire model glass box (Figure 4).

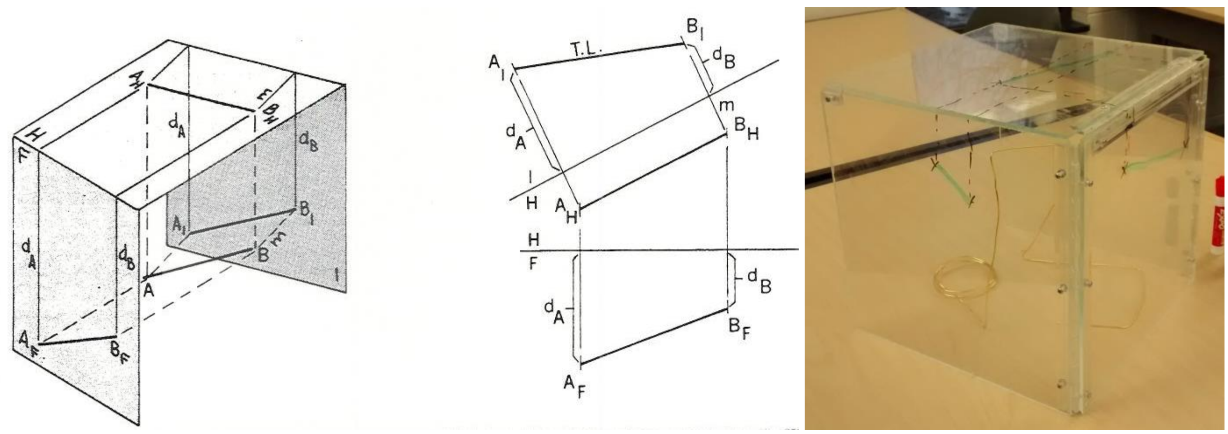

Figure 4 Use of wire model in glass box for descriptive geometry problems

These hands-on class activities are done in four steps (Figure 5). (1) Creating the wire model of the problem: Students are asked to create a scaled model of the problem using a flexible wire. (2) Observe and measure the projection view of wire model inside the glass box. They try answering the question whether the projection view is different if the model is observed from a different angle. (3) Students sketch the missing projection view on the paper that shows the true length and shape of the geometry. (4) Solve the problem by measuring the scaled drawing and calculating the true length.

Most of the engineering graphics courses neglect the hands-on class exercises and use only the computer representations. Positive effects of tactile class activities with foam and wire models have been observed in this study based on the test scores.

5. Methods for assessing spatial skills

There are several standardized tests available to measure a student's spatial skills[3235]. In this study, Vandenberg and Kuse's[36] mental rotation test (MRT) is used to gauge students' spatial visualization improvement. This test is one of the most commonly used measures of spatial ability. Mental rotation is the process of imagining an object being rotated into a different orientation in space. The students were asked to compare objects represented as 2D images on paper and to find the identical ones within a set of multiple choices. The only difference between the original image and the identical ones is that they are depicted at different orientations.

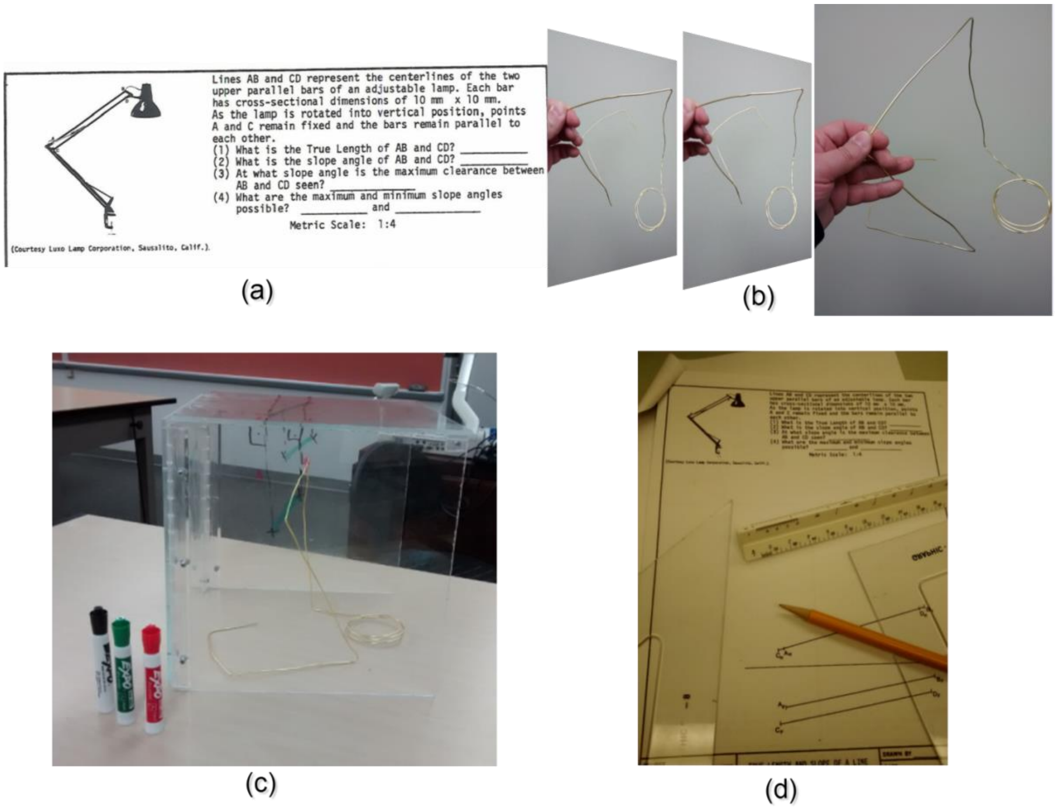

Figure 5 Hands-on class activities (a) descriptive geometry problem, (b) creating a simple wire model of the problem, (c) observing the wire model in glass box, and (d) drawing projections on the paper

Test was given to the students at the beginning of the semester and a second time before the final exam. Test scores are given in Figure 6. The correlations among student academic performance and spatial visualization ability and positive effects of training were investigated.

ET011 had 55 students in two sections in Fall 2014. Data is filtered to include only the scores of fully participated students in this study. Grades were adjusted to remove components such as attendance, group assignment grades, and project participation, as well as bonus points unrelated to the hypothesis. Arithmetic means of pre- and post- MRT scores of 62% and 81% respectively show increasing gain of spatial visualization after training. Positive effects of board drawing and tactile class activities with foam and wire models have been observed in this study based on the test scores. Authors observed greater improvement between pre- and post-MRT scores in this course with board drafting with hands-on activities, two dimensional (2D) CAD, and three dimensional (3D) CAD compared to a similar engineering graphics course with only 3D CAD application[37].

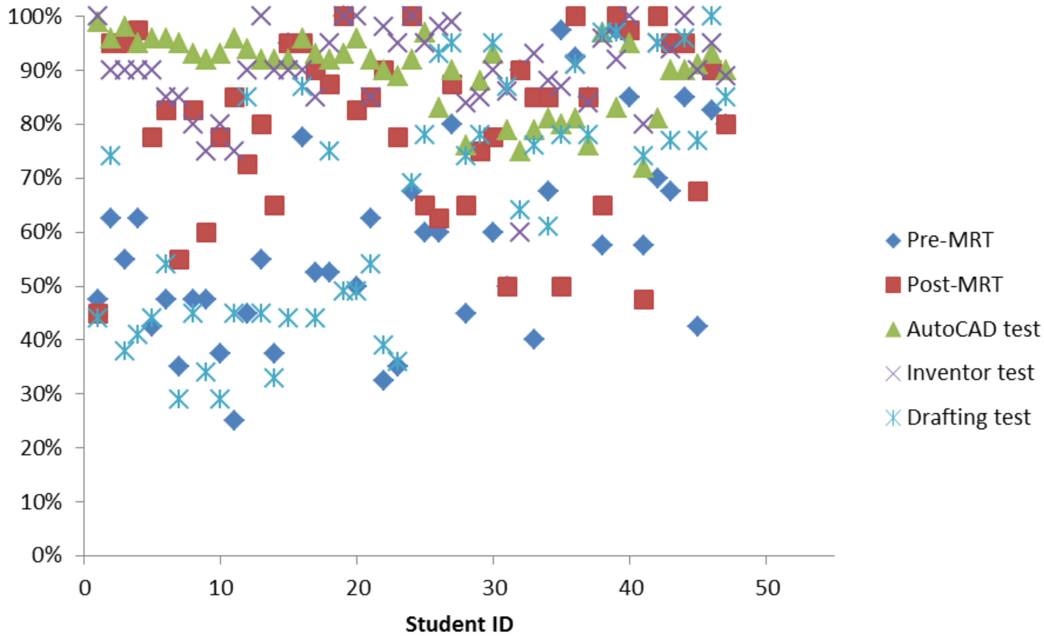

Figure 6 Test scores

Pearson product moment correlation coefficients for correlations among student academic performance and MR test scores are given in Table 1. Pre-test gives information about the students' spatial visualization ability based on previous experiences. Existing correlations are remarkable among spatial visualization ability and academic test scores. There is a stronger correlation among MR and board drafting test scores, than 2D and 3D CAD test scores. After training, post-MRT scores are relatively higher and therefore correlation coefficients are closer among the all three sections of the course.

Table 1 Pearson product moment correlation coefficients

	AutoCAD test	Inventor test	Drafting test	Gaming experience
Pre-MRT	-0.279	0.120	0.526	0.316
Post-MRT	0.143	0.195	0.119	0.109
Gaming experience	-0.076	0.109	0.146	1

Students were also asked if they are involved with art and sketching, or play video games in order to investigate if sketching and gaming activities improve spatial visualization ability.
Notably, students with the greater than average gaming activity experience have correlations to higher spatial visualization ability. Gaming activity leads higher academic success in 3D CAD and board drafting tests. There is no noticeable correlation between gaming activity and 2D CAD scores.

6. Conclusion

The ability to visualize in three dimensions is a cognitive skill that is linked to success in engineering. Effects of spatial visualization ability in academic performance in engineering drawing were investigated. MRT is used to measure spatial visualization skills. Different meeting times, instructors, and other circumstantial considerations would also impact test scores, but current study shows that spatial visualization skills positively affect student learning. Another interesting finding is that gaming experience of students affect hand drafting and 3D-CAD drawing test scores. Surprisingly gaming experience has no or weak relation to academic success in 2D- CAD drawing. There is not enough statistical evidence available to prove or presume any conclusion to justify this result. It will be investigated with further survey questions in the future. Positive effects of hands-on class activities with foam and wire models have been observed in this study based on the test scores. While enough data for a statistical analysis have not been collected yet, post-MRT scores demonstrate promising benefits after hands-on activities with foam and wire models. Pre- and post- MRT scores of 62% and 81% respectively show increasing gain of spatial visualization skill after training. In addition, it was found that the hands-on activities increase the students' interest and awareness in descriptive geometry.

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