2006-1271: USING SOLID MODELING AND MULTIMEDIA SOFTWARE TO IMPROVE SPATIAL VISUALIZATION SKILLS

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Abstract

The ability to visualize in three dimensions is an important skill for engineering and technology students. Unfortunately, there is little guarantee that students who enter the university possess acute spatial abilities. It was a common belief that spatial visualization skills are developed through life experiences and could not be effectively taught by instructional methods. Recent research refutes the life experiences concept and suggests that students who are exposed to appropriate learning environments improve their spatial abilities. This paper describes how the teaching methodology we have adopted in an introductory graphics class has helped students develop spatial visualization skills.

An interactive multimedia software based on work by Sorby and Baartmans[1] and a 3D sketch-based solid modeling software (Pro/Engineer) were utilized in the class. The interactive media provided students with the opportunity to gain fundamental understanding of orthographic projection, rotation about one or more axes, reflection and symmetry. Pro/Engineer was utilized to create solid models and project them at different angles, enabling students to realize various mental visualizations. Preliminary assessment of the class indicated that combining the interactive media and the solid modeling software was effective in the development of spatial skills in undergraduate engineering and technology students. The assessment also indicated that merely working with 3-D solid modeling software does not improve students' spatial skills. However, a students' spatial skill is significant factor in his ability to interact with a 3-D solid modeling environment.

Introduction

Spatial Visualization is defined as the ability to visualize an image of an object and then manipulate it mentally. Spatial Visualization has significant practical application in fields such as mathematics, physics, architecture, engineering and design. Spatial abilities have been widely studied and are known to be fundamental to higher-level thinking, reasoning, and creative processes. Due to its relevance, ensuring high spatial visualization ability among students is therefore desirable. Consequently, the most logical place in an undergraduate curriculum to incorporate learning strategies to improve engineering and technology students' spatial visualization is in introductory engineering graphics[2].

As the first course taken by most students, Engineering Graphics presents a challenge. Basic concepts in graphics and design need to be covered while helping students to develop or refine their visualization skills. In addition, the course must provide students opportunity to do creative and interesting work in order to get them excited about graphics and design, regardless of their intended major. Traditional approaches to engineering graphics using 2-D drafting and orthographic projections do not accomplish goals of providing creative and interesting work, and are unlikely to help students develop visualization skills if they do not already possess them[3].

This paper discusses techniques and strategies used in an engineering graphics course to augment students' spatial ability. The class is offered as part of an engineering science curriculum. It is 2-credit 4-hour a week class. Its main goals are to teach the fundamentals of engineering graphics as well solid modeling in an introductory environment. The objective of the class is to prepare students for design process and product realization skills demanded in an engineering curriculum. The syllabus covers topics such as: Sketching, Solid Modeling, Geometry, Multiviews & Pictorial Projections, Visualization, Sectional Views, Auxiliary Views, Constraint-based Modeling, Dimensioning & Tolerances, Manufacturing Processes, and Assemblies[4].

The curriculum provides an environment where project-based active learning is encouraged. The project-based component is composed of learning cycles. Each cycle begins with introduction to a concept, followed by physical exercises (observation) with objects or parts in which the concept is most relevant to promote experiential learning, followed by home work assignments to further promote the concept and culminated by a group project where a few of the concepts covered are utilized. The class teaches students to be designers, who approach open-ended problems with an organized solution method and a good set of supporting tools, not to train them to be technical drafters. Moreover, spatial visualization is incorporated into the curriculum both explicitly in topics such as solid modeling and visualization and implicitly in other part of the curriculum such as multiview projections and assemblies.

Factors Contributing to Spatial ability

There are differences in spatial visualization ability and its acquisition. They have been attributed to a number of variables, including: cognitive development, life experiences, gender, and aptitude[5]. Spatial experiences, acquired through life experiences or formal education, have been suggested to contribute to differences in spatial visualization ability. It is a multifaceted ability; any attempt to improve it may influence the acquisition of one aspect of it while not the others as demonstrated by Zavotka[6]. She found that while her students improved on their orthographic projection skills after following a program on computer-animated graphics, they however, do not improve on their mental rotation skills.

Spatial ability research has indicated that there are three factors associated with spatial ability: Mental Rotations, Spatial Visualization, and Spatial perception. It has also become apparent that it is possible to improve the spatial ability of students as described by Smith[7]. He further suggested that these elements can be effectively embedded into a curriculum that promotes understanding of engineering graphics and augments students' spatial skills.

CAD and interactive multimedia software

Contemporary CAD systems lend themselves to a certain geometry creation process and strategy formation on the part of the user. Sketcher-based modeling procedures depend on a user's ability to recognize the forms that make up an object and mentally dissect the features of that object into their constituent elemental cross-sections. They require that user sketches a representative cross-section corresponding to a feature of the object being modeled, and then apply a 3D form to that sketch. This process is repeated in an iterative fashion until all of the object's geometry is created[8]. In addition, current CAD software packages provide a light source that casts shadows on the object. This capability helps students perceive an object from its line representation. Moreover, current CAD software allows the user to rotate the model on screen, which helps students, who are able to perceive the 3D object represented in 2D space, but cannot mentally rotate the object[9].

Multimedia is defined as any combination of text, graphics, sound, animation, and video delivered and controlled by the computer. Interactive multimedia is defined as non-linear multimedia, that is, any tool that gives control to the user rather than the computer. In general, multimedia has been relatively successful because it draws upon more than one of the five human senses, utilizing the two fundamental senses vital for information reception – sight and sound[10]. Many educators have employed interactive multimedia in the engineering graphics design curriculum with success in improving the mental rotations aspect of spatial ability. Virtual reality augmented tools have also been shown to improve spatial ability. Literature search indicated use of such tools in variety of settings. They generally allow the user to rotate models generated using CAD software[9] or using a web-based virtual reality environment[11].

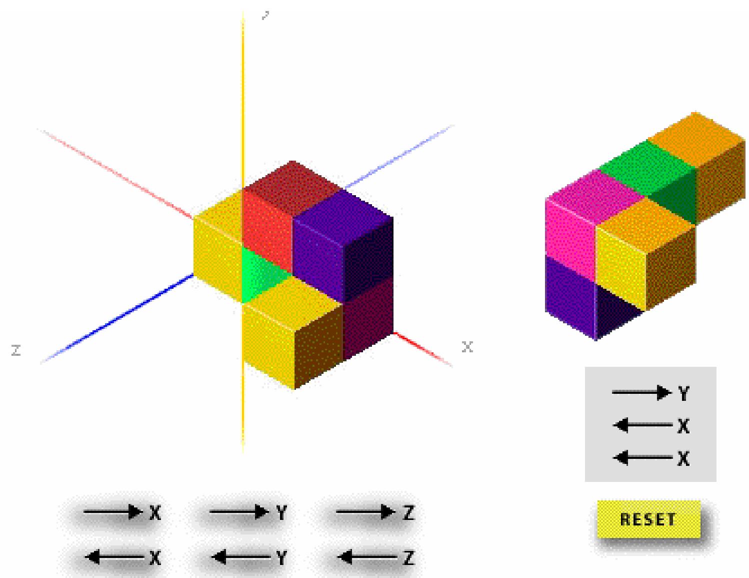

Fig. 1 Example from multimedia software; single rotations about axes

Solid modeler CAD and interactive multimedia application

Our strategy for improving students' spatial ability consists of two tracks; one is application of multimedia software and a workbook[1,12], supplemented by in-house developed exercises; two is application of 3-D solid modeling software Pro/Engineer. In the first, students are assigned exercises from the workbook and are encouraged to work through the multimedia software exercises. Fig. 1 presents an example of a rotation exercise from the multimedia software. The software allowed students to see the results of each rotation. The multimedia software concentrated on simple cut cubic models. It did not include any models with inclined/oblique surfaces or cylindrical volumes. The model's coordinate axes stayed unchanged in rotations, which was in contrast to the solid modeler software used in the class. These exercises were supplemented by in house developed ones, which focused on rotation with and without coordinate axes, and surface development.

Figs. 2a and 2b show samples of in-house developed rotation exercises. The focus was essentially on rendered solid and shaded models. Students realized mental rotation and surface development more effectively when viewed as rendered solids than wire-frame models. About half of the exercises on rotation included the coordinate axes. Adding coordinate axes to these instructional materials as well as sketches made on the board actually helped some students establish a mental reference to realize the rotation more efficiently.

Fig. 3 presents some of the surface development exercises that were introduced in the course. The surface development exercises concentrate on volumes that are formed by folding two-dimensional patterns. Solid lines on a flat pattern represent fold lines. The exercise requires students to construct a three-dimensional object from the pattern by mentally folding the pattern along the fold lines. The supplements focused on patterns that fold into solids with inclined/oblique or cylindrical surfaces; the workbook did not have many examples. Solid shading and color were utilized to create a more complete picture of formed solid. These exercises strengthen the student's ability to mentally visualize an object from its side views. This ability becomes very useful in creating sketch-based solid modeling software.

Our other strategy is to utilize solid-modeling CAD software capability to project solids at various states of rotation. We employ Pro/Engineer as the main teaching tool. Figs. 4a and 4b show the software interface for projecting models (wire-framed in Fig. 4a and rendered model in Fig. 4b). Single rotation about an axis or many rotations about axes are possible. The software has the coordinate axes attached to the model. Rotations about axes inherently rotate the coordinates as well. This is contrary to the multimedia software where the coordinate axes remain unchanged when rotations take place. To minimize ambiguity, we promoted both approaches.

In creating a model, a sketching plane is selected. Pro/E will then re-orient the user into a 2D view of the chosen plane. The user must be able to ascertain the sketching plane orientation relative to the object in order to avoid sketching the profile in the wrong orientation or position. It requires the students to be able to mentally visualize the path of the sketching plane through the portion of the object they are creating. This process requires a great deal of spatial ability and can become difficult when modeling an object that does not physically exist.

To become proficient, students model many objects. We start with simple cut cubes and progress to complicated geometry involving swept curvature. Students must mentally dissect the object and create sketching planes to form the desired geometry. This process implicitly strengthens students' visualization, emphasizing projection at various angles.

Toward the end of the term open-ended modeling projects are assigned. They allow understanding of the inner-workings and the potential options available to the user while practicing the tools and techniques of their future profession.

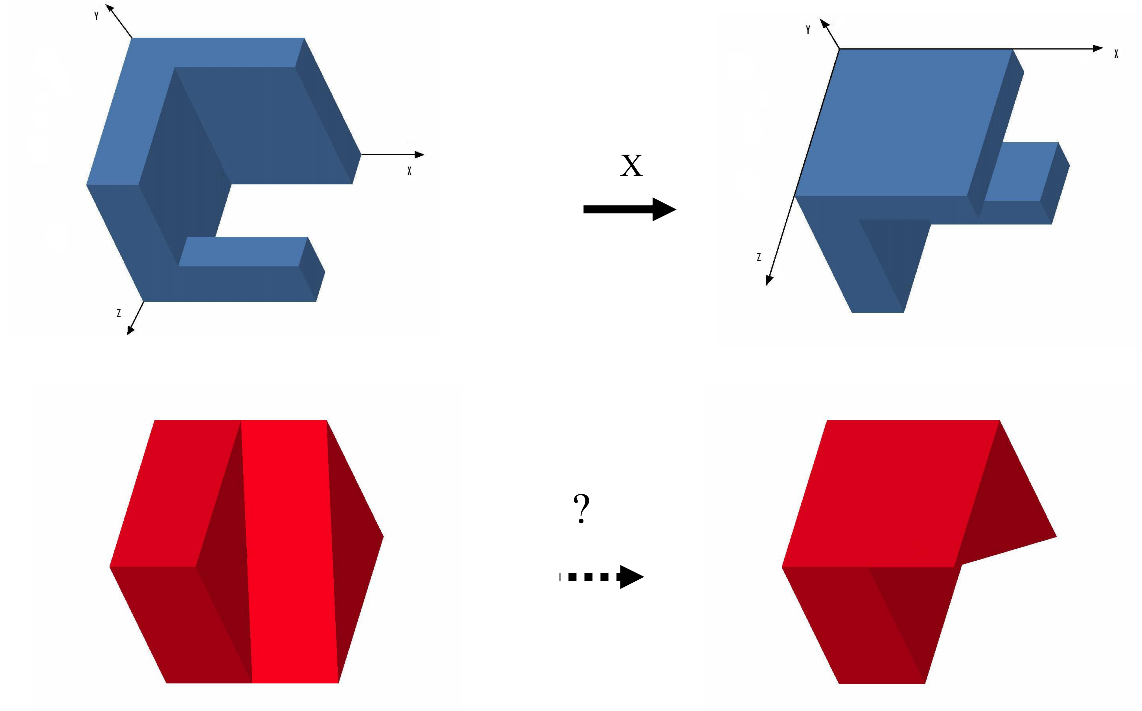

Fig. 2 a Single Rotation about a single axis (X-axis), top; attached coordinates systems

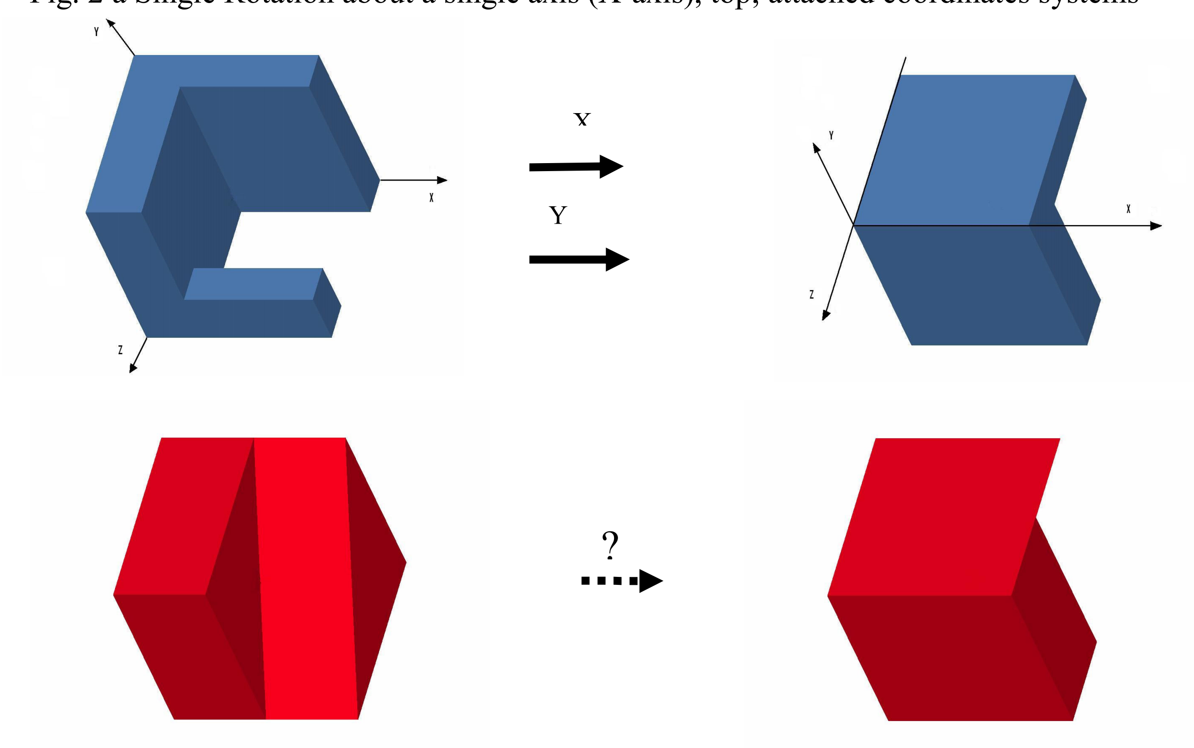

Fig. 2 b Single rotations about multiple axes (i.X-axis, ii. Y-axis)

Some students did not associate spatial ability with skills they deemed necessary to succeed in graphics education. This led to lack of motivation to spend time with the multimedia software. The mental and visualization rotation exercises were presented early semester. Toward the end of term when the solid modeling project became more demanding, the students realized the significance of improving this ability.

Impact of the Course

The effectiveness of the class on students' spatial ability was measured by comparing their scores on PSVT rotation and surface development components after they had completed the class (treated group) to other students that had not taken the class (control Group). Analyses of the scores are given in Table 1 and are also compared graphically in Fig. 5.

	PSVT rotation (max grade 30)	PSVT surface development (max score 12)
Student after completing Graphics Class (treated group)	(n=19) Mean= 22.2 Std dev= 5.4	(n=19) Mean= 8.7 Std dev= 3.2
Students who did not take Graphics Class (control Group)	(n=11) Mean=16.1 Std dev = 7.1	(n=7) Mean= 4.6 Std dev= 3.2

Table 1. Mean and Standard deviation for PSVT scores for treated and control groups

The test scores indicate remarkably significant differences between the two groups. The mean score of students after completing the graphics class on PSVT R is 38% more than the students who did not get exposed to the spatial ability instruction. The mean score of students after graphics class was 89% more that the other group in PSVT surface development test. Although the sample sizes were small: 19 and 11 in PSVT R, and 19 and 7 PSVT SD, the differences were so pronounced, that they led us to conclude that by completing the graphics class students spatial ability, as measured by these two components of PSVT are indeed improved.

Students scores on PSVT were cross correlated with their class design projects. The analysis revealed students with higher scores in PSVT executed more complex and challenging projects during the semester than those students who scored lower. This indicated they gained more from the curriculum and mastered the software more efficiently. No pre-test was administered to determine whether students with more challenging projects entered the class with higher spatial ability. However, based on their examination grades, we were able to ascertain higher spatial ability in the beginning of class. On the other hand, students who scored low on PSVT generally could not follow the course content and did not master the software as efficiently as those with higher PSVT scores. This indicated that high spatial ability is a requisite to master the solid modeling software efficiently.

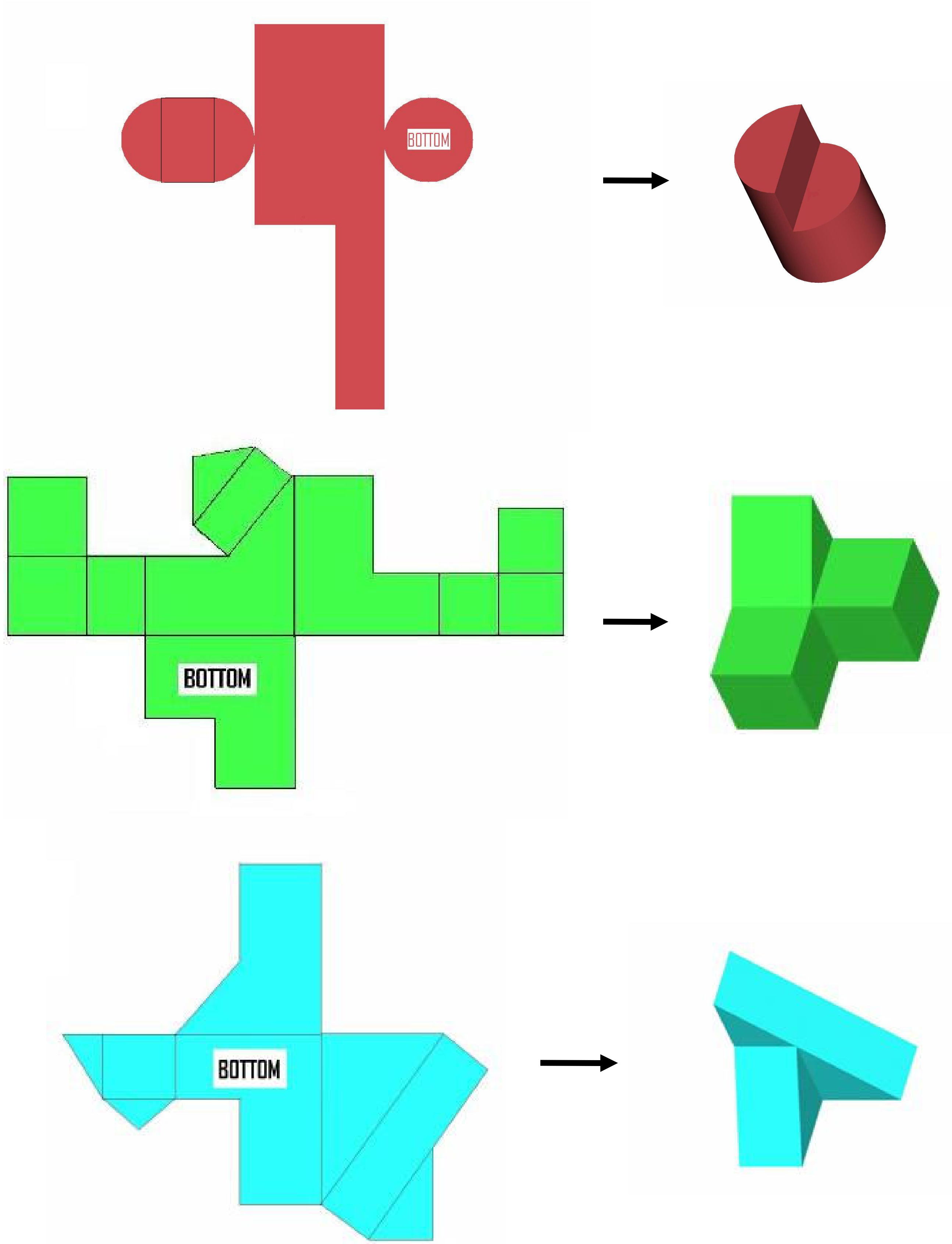

Fig. 3 Surface development exercise with i. Cylindrical, ii. Normal and inclined and iii. Inclined surfaces

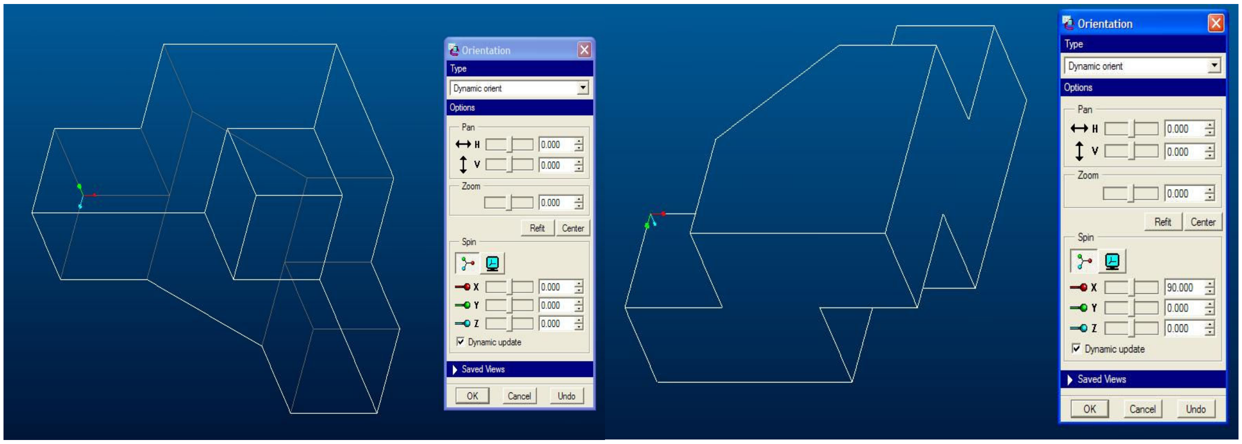

Fig. 4a Rotation of wire-framed solid about x-axis using Pro/Engineer software

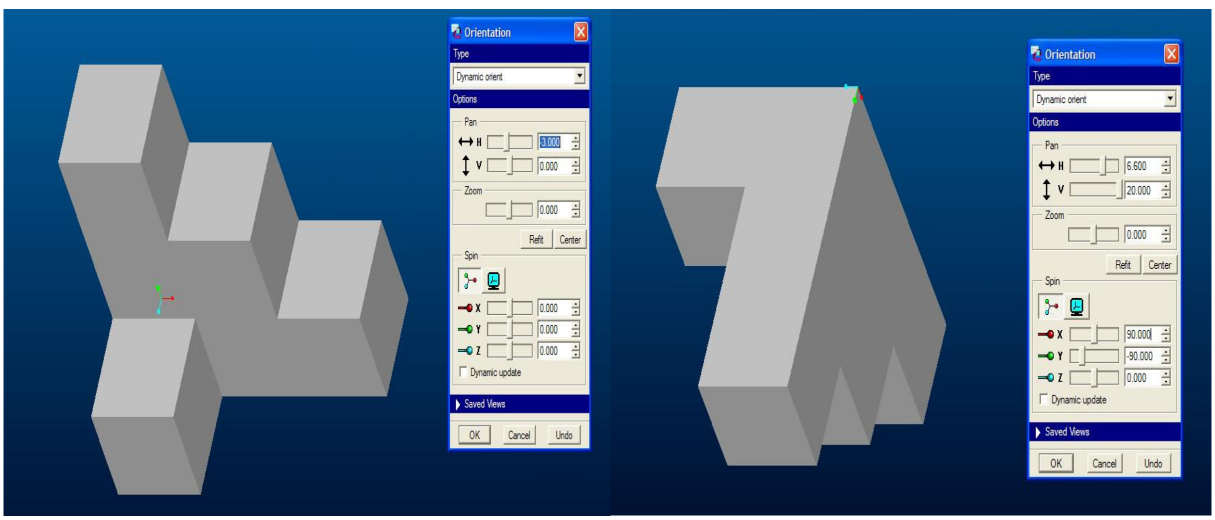

Fig. 4b Rotation of rendered solid about multiple axes using Pro/Engineer software

Conclusion

The introductory graphics class aims to teach fundamental concepts of engineering design graphics. It introduces students to constrain-based three-dimensional solid modeling software. The class also aims to improve students' spatial ability. It uses interactive multimedia software to teach Mental Rotations and Spatial Visualization. Students' spatial perception was augmented by learning to use the sketch-based solid modeling software. The data presented in this paper indicated that the methods employed in the class are effective at improving spatial skills. The improvement was achieved without a significant reduction in course content.

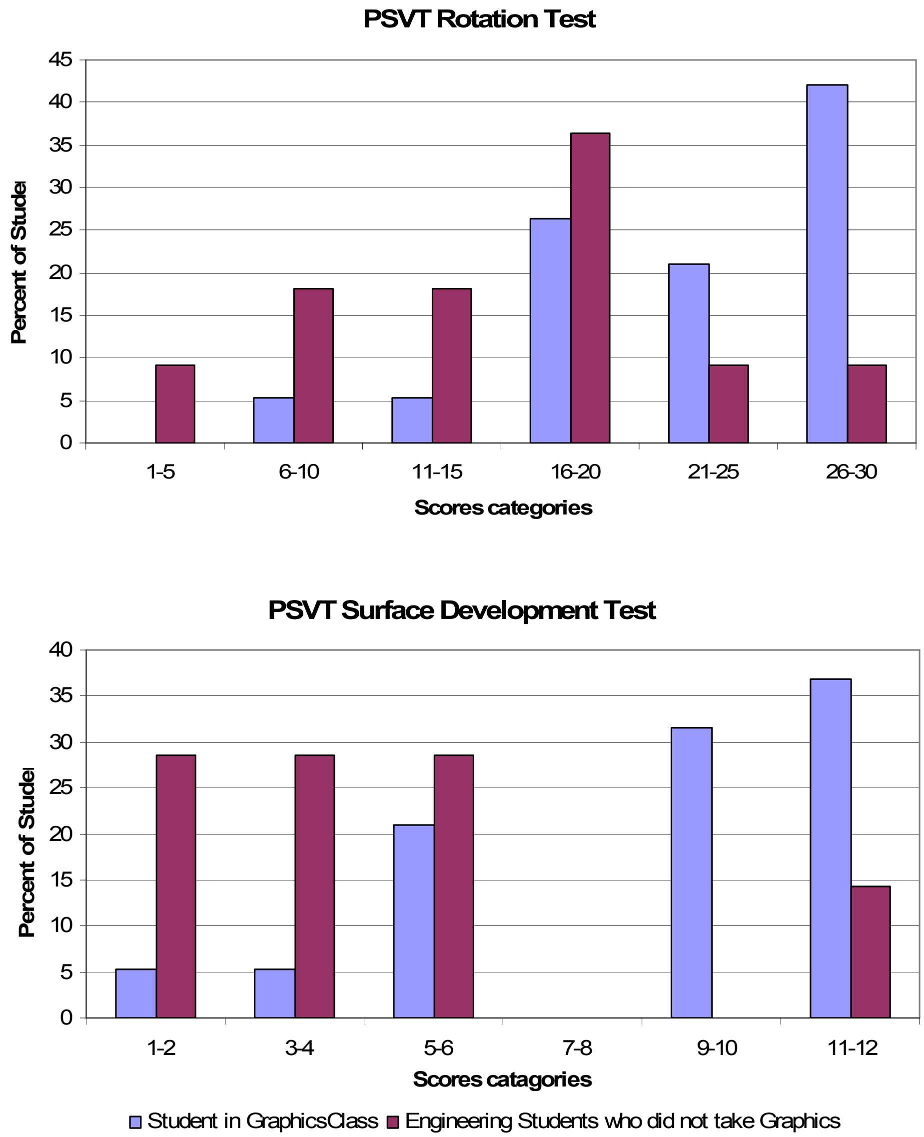

Fig. 5 Post-test graphics class, PSVT R and surface development tests

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