Integration of Augmented Reality into the CAD Process

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Abstract

The enhancement of visualization skills of engineering students is essential for their development of design skills in many fields of engineering. Based on studies of visualization skills of entering first year engineering students, some of them have difficulties in dealing with orthographic applications (projections, orthographic to isometric transformations, etc.). They seem to lack sufficient geometric and/or trigonometric relational skills, both of which are essential when modeling even simple geometric objects. Augmented Reality (AR) technology could provide a solution to this problem. The potential benefits of AR are improvements in the students' abilities with respect to spatial cognition, concept development, decision making as well as design modifications and refinements due to the support for viewing and 'touching' the design.

This paper will explore the integration of AR into the Computer Aided Design (CAD) process with SolidWorks software in order to provide an interactive learning experience, in which abstract thinking is supported and concept visualization, exploration and evaluation are facilitated during the various stages of the design process. Such an AR system will permit the students to visualize virtual representations of their 3D CAD models in real-world settings by mixing the 3D CAD model with a webcam view of the students and facilitating real-time interactions between the students and the designed objects.

1. Introduction

Engineering graphics skills are considered to be an essential characteristic for undergraduate engineers in an era of rapid economic and information technology advancements all over the world. From this perspective, engineering graphics educators have developed a variety of approaches to improve the 3D visualization skills of entering first-year engineering students, ranging from the use of drafting tables and T-square rulers to modern solid modeling using computer aided design (CAD) systems. [1,2] Starting in the late 1980s, along with an increase in the capabilities of personal computers, educators have led the replacement of hand-held instruments by CAD systems as tools for facilitating learning of engineering graphics. CAD systems involve the use of computer hardware and graphics software to generate engineering design drawings. The computer hardware provides an excellent environment that allows for the development and delivery of both static and dynamic media much more readily than in the past. [3,4] Graphics software enables students to lay out and develop designs on a computer screen, print them out and save them for future editing, all while saving time on their drawings in the process. Modern CAD packages also allow rotations in three dimensions, thus enabling the viewing of a designed object from any desired angle, even from the inside looking out. As a result, nearly all engineering schools have eliminated courses in descriptive geometry, manual drafting and sketching in their curricula. As a result, there has been a noticeable decline in the visualization skills of engineering students. [5] It has also been found that the content of current graphics courses tends to focus more on how to use the CAD software instead of teaching the fundamentals of engineering drawings. Recent studies [6,7] indicate that a 3D CAD experience alone provides limited real-time 3D interactions for students and thus does not seem to enhance the students' visualization skills.

For this reason, even though powerful computers and software are available nowadays, developing visualization skill is necessary for imagining, specifying and creating complex

designs with functional features in the three spatial dimensions. Current Augmented Reality (AR) technology can help to improve design and visualization skills, aid in scientific simulations and serve as a tool for education or entertainment. AR technology typically provides visualization aids that bridge the gap between physical prototypes and digital computer models. Today, AR technology provides solutions and benefits in numerous application areas such as space training, medical education, manufacturing, visualization, assembly training, entertainment and military training. For example, Boeing researchers found that AR technology can provide an effective method for simulating many possible scenarios and multiple configurations without the need to fabricate physical artifacts (see Figure 1-a).[8] Boeing has recently started to use AR as a tool for assembly training because it can help to reduce training needs and communicate complicated technical instructions. Boeing is also leading efforts to create an AR demonstration project on the International Space Station that aims to demonstrate to NASA the advantages of AR in terms of savings over traditional training methods (replacing time-consuming task-based instruction with skills-based training while significantly decreasing training, operations and logistics requirements). This project will help astronauts to access an AR library that can be updated by ground crews, allowing them to go through the refresher steps of performing critical space tasks.

In addition to Boeing, car manufacturers are creating AR environments that mimic a new car model's interior where users can examine the interior freely, almost as if they were physically sitting inside the car. BMW and Volkswagen are using AR technology to visualize and modify the car body structure and engine layout (see Figure 1-b).[9] They are also incorporating this technology into their assembly lines to improve their manufacturing and assembly processes. Volkswagen uses AR for comparing calculated and actual crash test imagery, analyze interfering edges, plan production lines and workshops, compare variance of the vehicle parts and verify part dimensions. AR can augment the effectiveness of navigation devices. Information can be displayed on a car's windshield indicating information of where the user is going. In military training, AR can be employed as a third eye for a soldier to help him to figure out if there is someone on his back. In addition, with the usage of AR, a soldier does not have to stop to look at a map since the technology can indicate his location to him at all times without him taking his eyes off the field. In medical education, AR technology is employed as a visualization and training aid for medical diagnosis or health education.[10] It is possible to collect 3D anatomical data and health-related information of a patient using non-invasive sensors such as Magnetic Resonance Imaging (MRI), Computed Tomography (CT) scans, ultrasound imaging, sphygmomanometers or thermometers. These data can then be rendered and combined in real time with a view of the real patient (see Figure 1-c).

In the field of education, AR provides a means for generating visual models of abstract concepts.[11] It can help students in understanding chemistry by allowing them to visualize the spatial structure of molecules and interact with virtual models of them that appear, in a camera image, positioned at a marker held in their hand.[12] In mechanics education, PhysicsPlayground represents an AR application that allows students to simulate physical experiments in the domain of mechanics in real time.[13] Students are enabled to actively build their own experiments and study them in a three-dimensional virtual world. A variety of tools for analyzing forces, mass, paths of objects before, during and after experiments are provided. AR can also enhance the teaching of engineering graphics by enabling the students to visualize and interact with their designs in a more intuitive way.[14,15,16] The students can plan out the assembly process

concurrently and check for fitting and interference between components. This paper will discuss the technique used in an engineering graphics course to augment the students' spatial skills.
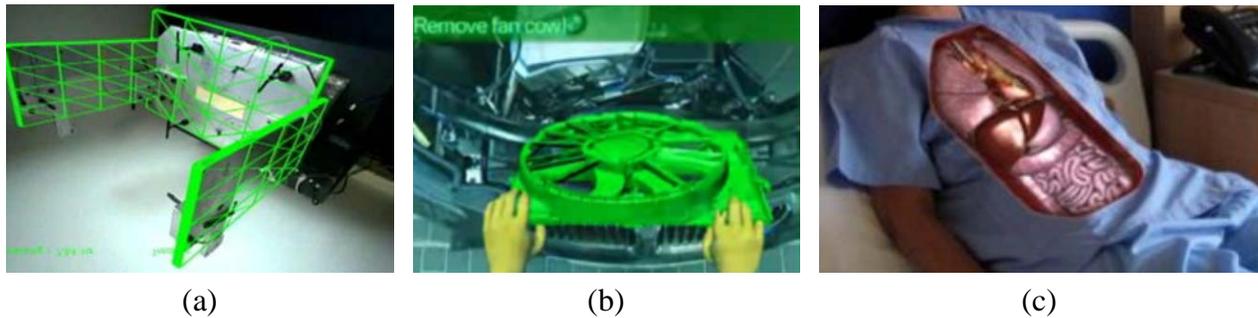

| (a) | (b) | (c) |

Figure 1: Examples of augmented reality applications

2. Augmented Reality System

AR systems generally require some indication of where exactly they should augment a digital image. This is most commonly accomplished with AR markers. AR markers are images that can be detected by a camera and used with software as the location for virtual assets placed in a scene. Adding AR markers can be as simple as printing a marker pattern and then placing the printout in the field of a webcam image that is running through AR software such as AR Google SketchUp[17], ARTag[18] or ARToolkit[19] in marker-based AR. When the markers are recognized by AR software, the computer is able to determine the position and angle of the marker. The software can then use this information to extrapolate the correct position and orientation of a virtual object as shown in Figure 2.

It is also possible to create an AR effect without using markers, which is known as markerless AR. Sony has developed markerless AR, which they call 'SmartAR'. Instead of using 2D markers, SmartAR can generate on-screen virtual images of everyday objects such as menus and posters. SmartAR technology uses 'object recognition technology' to achieve the markerless functionality and also Sony's own proprietary '3D space recognition technology', which they use in their research robots such as the AIBO robot. However, this new markerless AR technology has not yet been made available for public use.
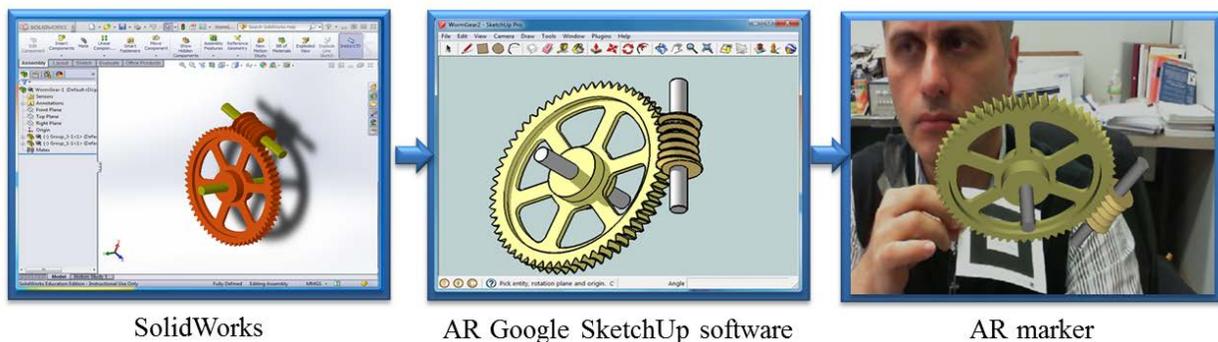

SolidWorks   AR Google SketchUp software   AR marker

Figure 2: 3D mechanical object is converted from CAD system into AR environment

3. Pilot Implementation

3.1. General Course Description

The engineering graphics course is offered as part of an engineering curriculum. It is a 2-credit 4-hours per week class. Its main goals are to teach the fundamentals of engineering graphics as well solid modeling at an introductory level. It is designed to expand the students' ability of visualization and to assist their mental process of developing and presenting graphical ideas for engineering applications and documentation. The course topics include hands-on construction activities alongside with computer activities such as sketching, solid modeling, drawing of projections and orthographic, isometric, sectional and auxiliary views, constraint-based modeling, geometric dimensioning and tolerancing, generating working drawings by specifying manufacturing processes and assembly.

3.2. Engineering Graphics Class

The class is conducted by beginning each session with a 25 minute lecture, followed by an assignment that is to be completed by the end of the class. The instructor and teaching assistant circulate in the classroom and assist the students. In the first week of this class, the language for engineers to graphically communicate is intruduced and tools to prepare engineering drawings are described. In the second week, sketching techniques and projection theory are intruduced. Projection drawings are developed to represent 3D images on 2D media and multi-view parallel projections are used in engineering drawings to visualize all three dimensions of the objects as shown in Figure 3. After practicing freehand isometric and multi-view sketching, the students are expected to hone their skill of visualizing orthographic projections. With this skill, they start to design 3D solid models and generate engineering drawings in CAD systems.
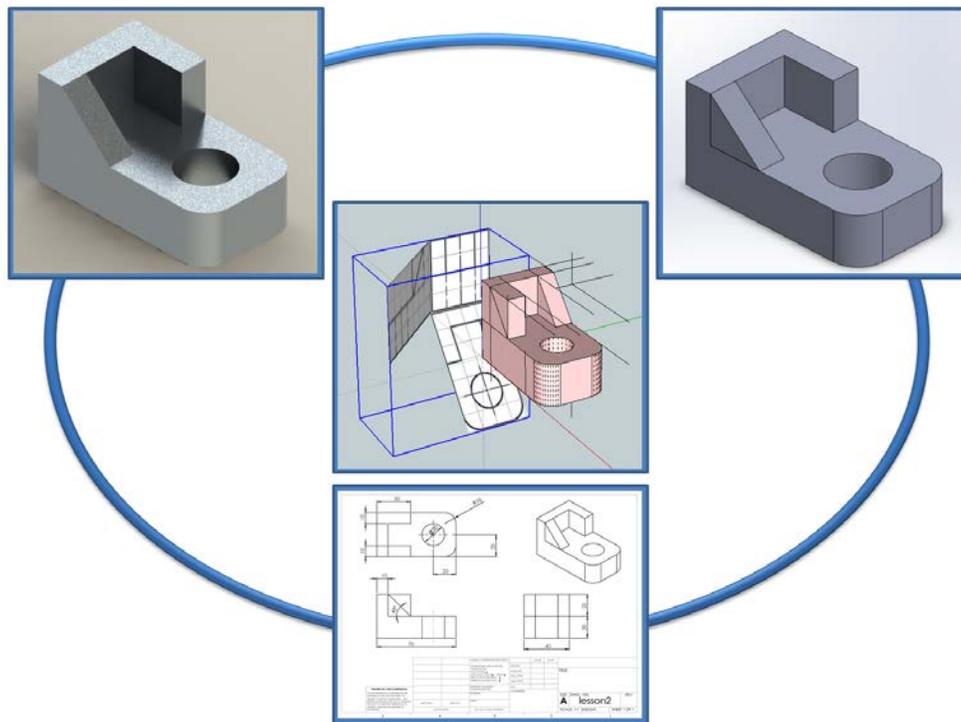

Figure 3: Visualizing a multi-view drawing

Third week is decidcated to section views and auxiliary views for engineering drawings. In the fourth week, part models are mated to create assemblies. Every week, 3D models are designed and dimensioning and tolerancing are practiced with the generated engineering drawings. After completing the course, the students are expected to be able to design 3D solid models by sketching with CAD systems as well as to generate and read 2D standard engineering drawings.

4. Case Study

Modern rendering techniques used in CAD systems help students to visualize their designed parts. However, spatial cognition of multi-view projections is still a challenge for some of the students. In order to address this issue, a mental rotation test[20] was given to the students during the first week of the course. Mental rotation is the process of imagining an object being rotated into a different orientation in space. This test is a traditional paper-based test. The students were asked to compare 3D 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.

In AR applications, the students can interact with real, physical objects around them while virtual models are being added to this world. Using this technique, they have a better perception of the objects they observe. The same mental rotation test was repeated with AR models to investigate the benefits of AR models in assisting the students' graphic and spatial cognition skills. The questions of the AR assisted mental rotation test were prepared from the paper test. The 3D virtual models for the AR assisted test were generated by using a CAD system. The CAD models were then converted to AR models by using AR software. In this way, 3D virtual models can be displayed on the computer monitor together with the test paper containing the questions (see Figure 4).
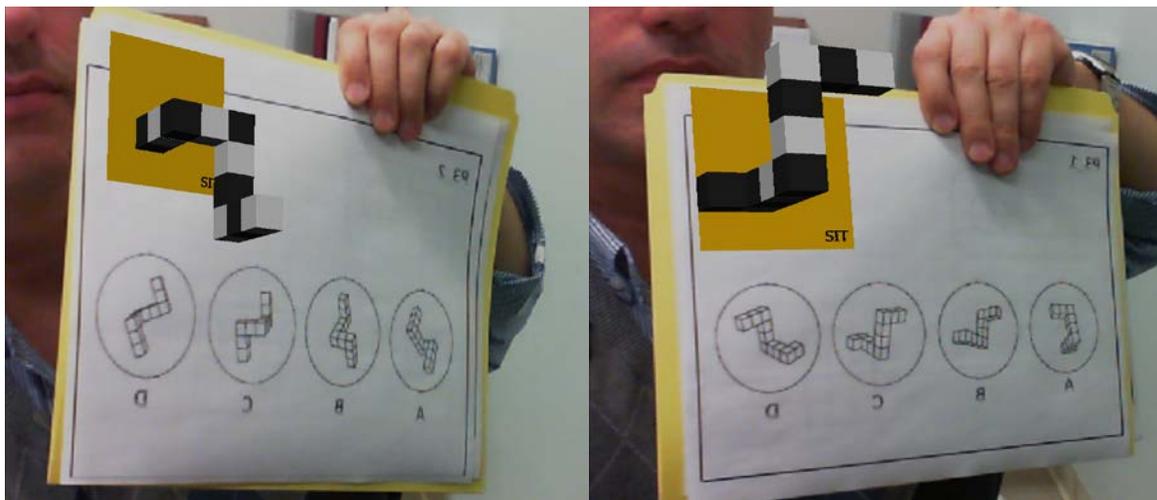

Figure 4: AR assisted mental rotation test

The AR assisted test questions were printed out with a special marker that was used to position the AR model into the webcam real-time video-stream. When the student moves the paper, the virtual object displayed on the paper moves with it, so that the object can be observed from any point of view.

While enough data for a statistical analysis have not been collected yet, the comparison between the regular and AR based mental rotation test results demonstrate promising benefits for AR in spatial cognition as shown in Figure 5.
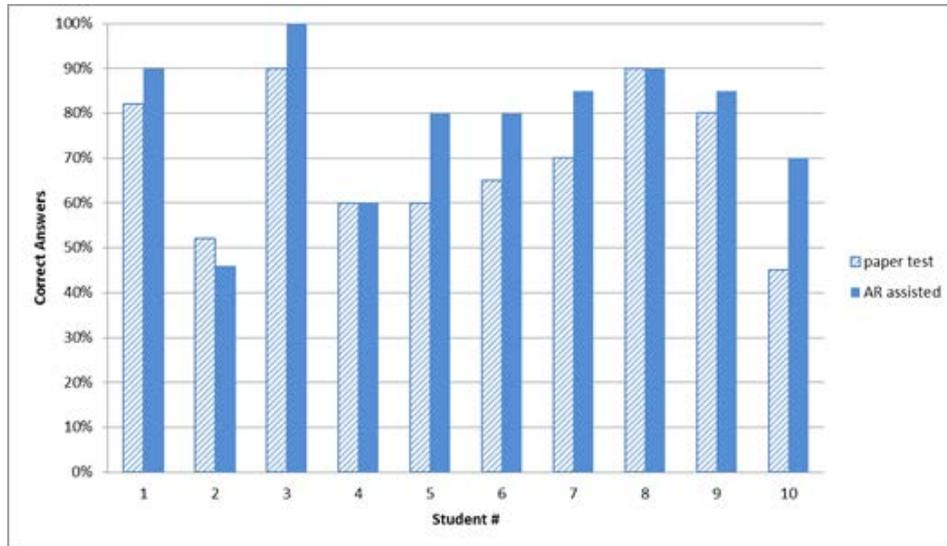

Figure 5: Comparison of mental rotation test results

In order to explore the benefits of AR in the CAD process, a set of activities with AR in the CAD system aimed at improving the students' spatial abilities were developed. In the first activity, the students were given an engineering drawing with three principal views and an AR marker as shown in Figure 6.
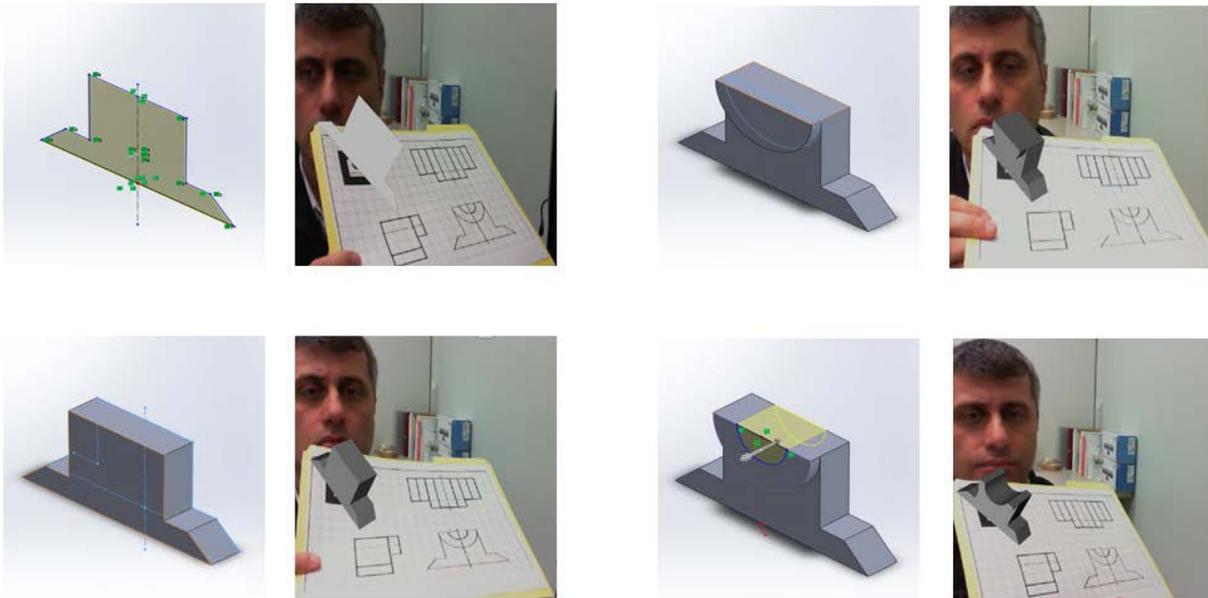

Figure 6: Engineering drawing with AR marker

Using this AR marker, the students can visualize the 3D object and manipulate the object by moving the drawing. AR models can be generated step by step by adding the solid modeling features one by one on top of each other in the CAD system. The model can be displayed on the screen using the AR system. This step-by-step modeling and visualization process will help the students' perception, and thus the students will have better skills to model complex parts. In the second activity, the students were able to check whether they can identify 3D objects from their orthographic views. Four similar objects were displayed on the screen using AR while the students were looking at the orthographic view of one of the objects. The task was for the students to select the correct object (see Figure 7).
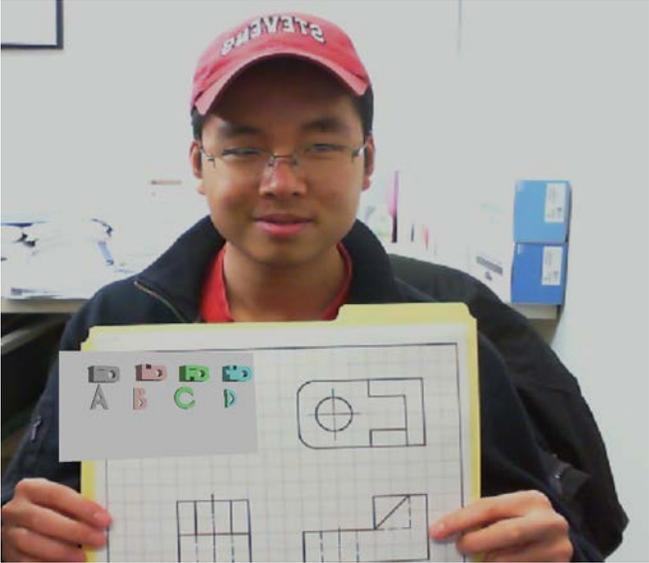

Figure 7: Selection of correct 3D object

The third activity was to identify the correct front view projection of a part. The students were then asked to select the matching front view from multiple choices (see Figure 8).
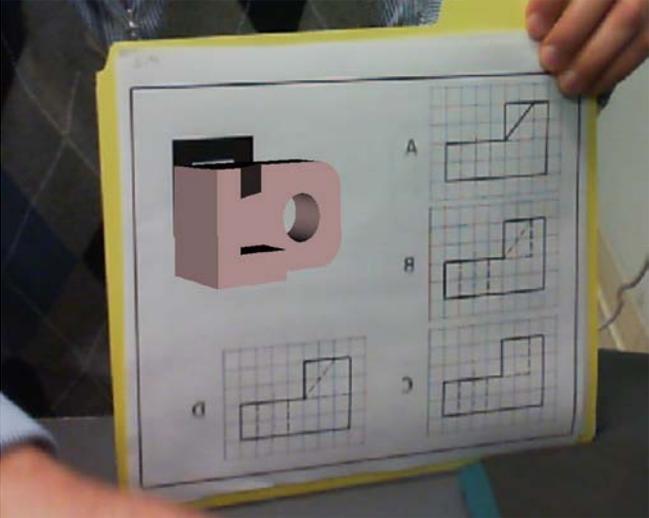

Figure 8: Identification of matching front view

Finally, a small group of students was asked to try the AR integrated CAD system at the end of the semester. After they successfully completed the activities, their feedback was very positive. Most of the students found AR interesting, easy and enjoyable (see Figure 9). The only negative comment was that the students were confused by the mirrored images on the screen, but after practice they were getting used to that feeling.
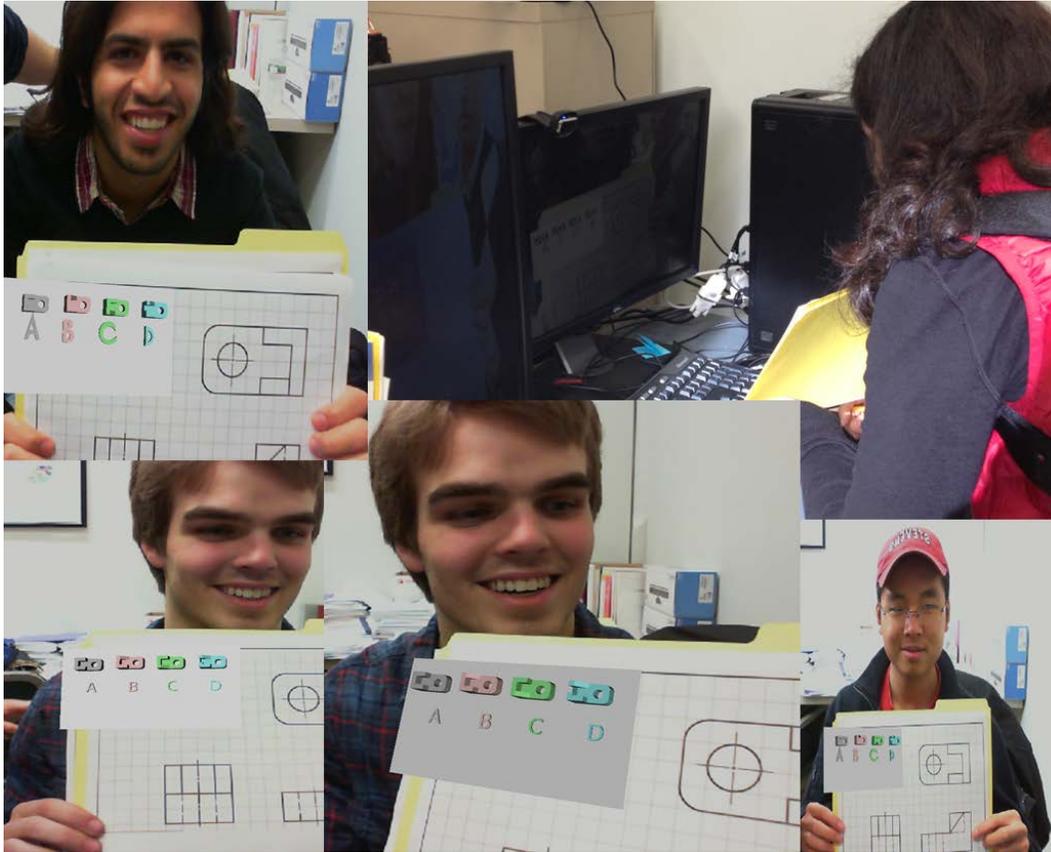

Figure 9: Students trying AR integrated CAD system

5. Conclusions

This paper examined the potential of an augmented reality system as an educational tool in an engineering graphics course. The students of that course were able to observe 3D objects on the computer screen in a real-world environment captured from a webcam, with a special AR marker on a traditional 2D engineering drawing. The developed AR interface can display different 3D CAD models and help engineering graphics students better understand CAD drawings, geometric features and projection views. In addition, it was found that the AR interface increases the students' interest and awareness in engineering graphics class assignments.

Acknowledgment

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