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Augmented Reality: Bridging the Inclusivity Gap in Engineering Graphics Education through Spatial Skills Enhancement

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Abstract

The Engineering Graphics course is a foundational course for engineering students, which covers freehand sketching and basic CAD modeling, CATIA. Many students, particularly students identifying as women or gender minorities and those who are socioeconomically disadvantaged, face challenges because the current educational approaches in spatial skills have not been designed to support students with diverse backgrounds and perspectives. Research has shown that spatial skills are instrumental foundation for high-level problem-solving and success in STEM, which have often been overlooked in K-12 education. It also indicated that spatial skills as cognitive skills can be improved if appropriate constructive exercises are offered to facilitate the learning process.

In this NSF-funded project, we aim to enhance Student's Spatial Skills Through Augmented Reality (SSTAR). This interactive, color-coded tool provides a step-by-step 3D learning experience, providing scaffolding and engagement while learning spatial skills. Students can scan images with smart devices to trigger 3D models with manipulable components for constructing the correct 3D models. They can also visualize different surfaces projected on the sides of a glass box offering 2D orthographic projection. Supplementary videos aid in understanding the conversion of 3D models between orthographic projections and isometric views.

The SSTAR employs color-coded surfaces within a virtual glass box, providing consistent markers for students to analyze lines and surfaces for a deeper understanding. It also integrates gamification elements, transforming the learning process into an engaging and interactive experience. Through the strategic use of distinct colors, it emphasizes the connections between lines and surfaces, allowing students to refine their spatial skills and approach problem-solving systematically.

Keywords

Augmented reality, AR, CAD, K-12, STEM, engineering graphics, spatial skills, gamification

Introduction

Engineering graphics course, as a gateway engineering course, is typically taken by engineering students in their first year. It covers freehand sketching of 2D and 3D representation of objects and basic CAD modeling techniques. Many students, especially students identifying as woman or gender minorities and those who are socioeconomically disadvantaged, tend to struggle in this course because their current educational approaches on spatial skills have not been designed for students with diverse backgrounds and perspectives[1] . For instance, women and gender minorities may have different experiences and perspectives that are not addressed by standard one-size-fits-all teaching methods. Female students and students from socioeconomically disadvantaged backgrounds may lack access to resources such as Lego or video games that can enhance spatial skills. This resource gap can put them at a disadvantage in courses that heavily rely on these skills. In fact, spatial skills haven been correlated to high-level problem-solving ability and linked to success in STEM [2]–[4]. Previous research has indicated that spatial skills have often been overlooked in K-12 education. It also indicated that spatial skills as cognitive skills can be improved if the appropriate constructive exercises to reinforce are offered [5]–[11]. With consistently low participation from historically minoritized groups in engineering, spatial skills provide a crucial opportunity to aid in recruitment and retention efforts among these students in engineering. Past research has shown a gender and socioeconomic influences in spatial skills, with evidence pointing to lack of support and exposure to these students before they enter college for engineering [3], [5], [6], [12]–[25]. The Glass-box method, cubes, physical models, videos, animations, and computer applications have been used to enhance students' spatial skills, but with limited success as these methods can only be used at certain locations with certain devices accessible [26]–[29]. Also, these methods including the smart device or Virtual Reality (VR)/Augmented Reality (AR) applications can only offer the final 3D look of the model in one color without interactive experience on how the 3D look was generated [30], [31]. Students often experience challenges when trying to visualize a 3D picture when faculty describe the location of the lines and surfaces in the orthographic projection verbally.

In this NSF funded research project, we plan to enhance Student's Spatial Skills Through Augmented Reality (SSTAR). This interactive, color-coded application provides a step-by-step 3D learning experience, providing scaffolding and engagement while learning spatial skills. Students can scan images with smart devices to trigger 3D models with manipulable components for constructing correct 3D models. They can also visualize different surfaces projected on the sides of a glass box offering 2D orthographic projection. Supplementary step-by-step videos with animations are provided to aid in understanding the conversion of 3D models between orthographic projections and isometric views.

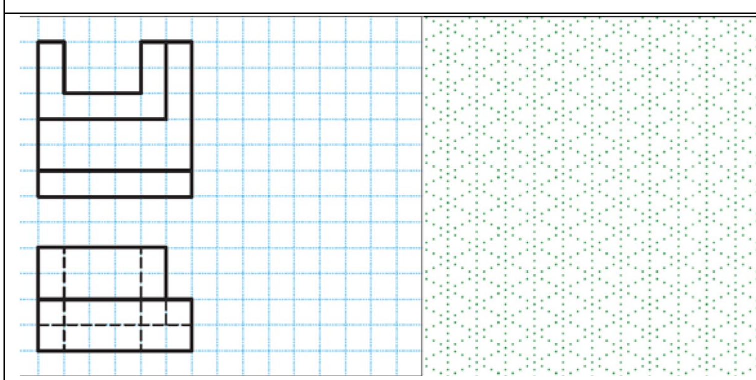
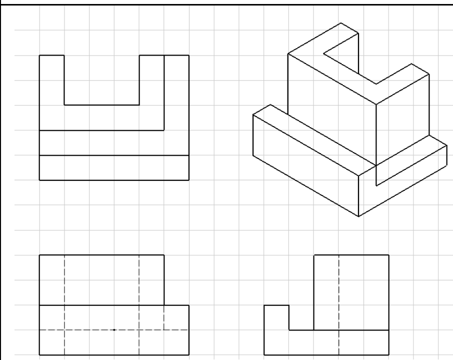
Furthermore, the SSTAR incorporates gamification elements, transforming learning into an engaging and interactive experience. By emphasizing the connections between lines and surfaces through color codes and interactive animations, students can build their spatial skills while solving problems. The proposed innovative approach enables students to develop proper spatial skills leading to effective study strategies and systematic problem-solving. This 3D immersive gamified learning can serve as a critical tool for student engagement and may contribute to retaining more females and low-SES students in STEM field.

The topics covered will include normal surface, inclined surface, oblique surface, cylindrical surface, section view, and auxiliary view. There will be 3 problems designed for each topic, which means a total of 6 topics and 18 problems. In this work-in-progress paper, the baseline model design in the SSTAR will be illustrated.

SSTAR Design

Table 1 shows one of the current EGR120 freehand sketching problem and its corresponding answer, which involves normal surfaces. The common issue is that students typically confront with challenges to use the relationship between the line and surface in the given views to locate the same surface in the isometric view. Since surfaces are all connected, when they misplace one surface, the locations of other surfaces will be misplaced. It is very hard to verbally explain the orientation of the surface on paper since it is challenging for one to orient, visualize and immerse themselves to figure out the connection between the surfaces. Our design approach is to scan the given orthographic projection by using a given tablet, and students can then encounter an interactive layout with individual components (color-coded based on the orientation of their faces) and the overall glass-box volume, which the users need as a reference. The goal for the users is to manipulate these individual components to assemble them into one 3D model, which offers consistent orthographic projection as given. As illustrated in Figure 1 students can choose from any available component to manipulate and place it onto the glass box volume. Each component is composed of three colors corresponding to the direction of the views. The colors are specifically selected to be color blind friendly. Once the selected component is placed within the volume in the correct position, the SSTAR will provide temporary feedback such as highlighting the component in green with call outs to confirm its correct placement and corresponding gamification points will be offered as incentive. This feedback will be displayed temporarily, as maintaining the original color-coding of the components is preferred. Students then have the option to either rotate the selected component around the X, Y, or Z directions, or translate it onto a different position. Figure 2 and Figure 3 illustrate the difference between the rotation and the transformation. These manipulations will be available for all components. Figure 4 shows the repeatability of all previous features applied on the second component. Additionally, the SSTAR will provide feedback when students place a component within the volume in the incorrect position or orientation. Figure 5 shows the difference between an incorrect placement in red and a correct placement of a component in green with corresponding callout. Students can accumulate gamification points as they place components in the right place for each problem. Accumulated gamification points can motivate students to practice more and improve their final grade at certain percentage.

Table 1 The current EGR120 freehand sketching problem and the corresponding current answer

Problem: Follow the given front view and top view to complete the missing right-side view and the isometric view	Answer with the completed missing right-side view and the isometric view
	

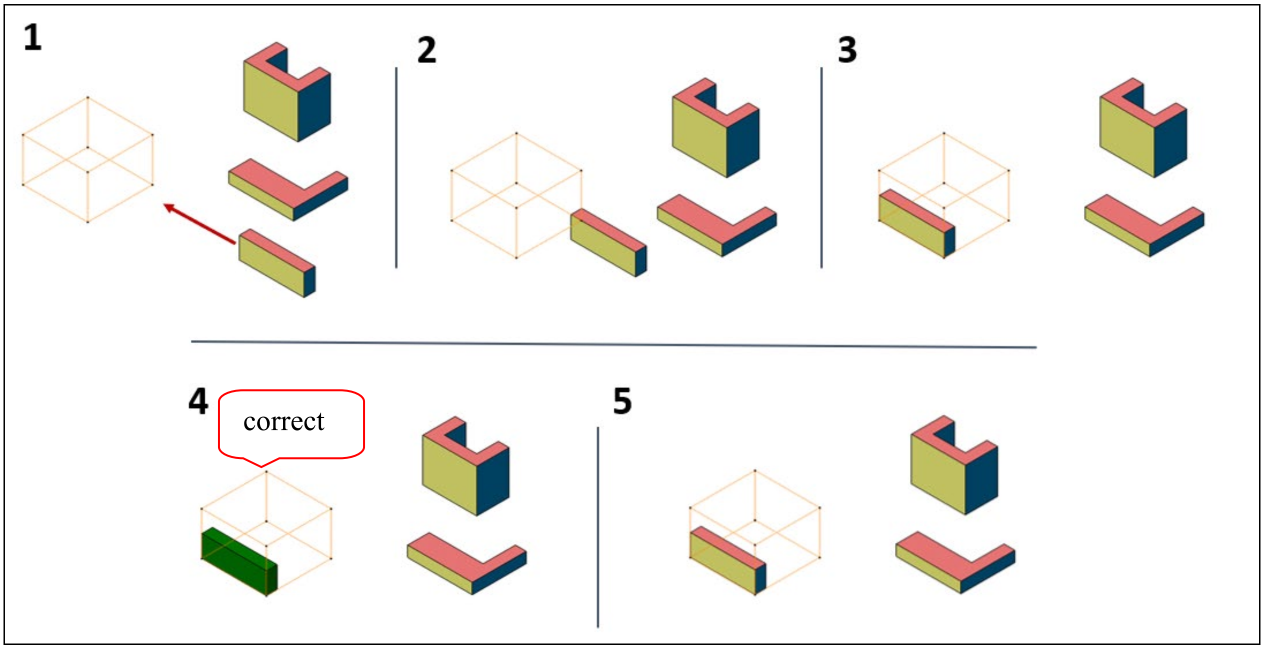


Figure 1. Component manipulation and placement onto the glass-box volume (1-3); temporary feedback to display correct placement (4); final layout before future manipulation (5).

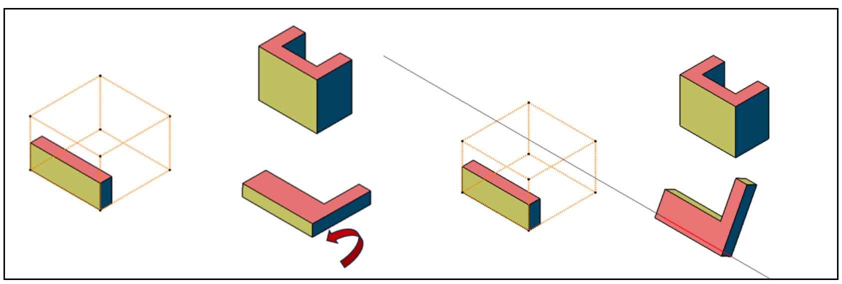


Figure 2. Rotation of a component.

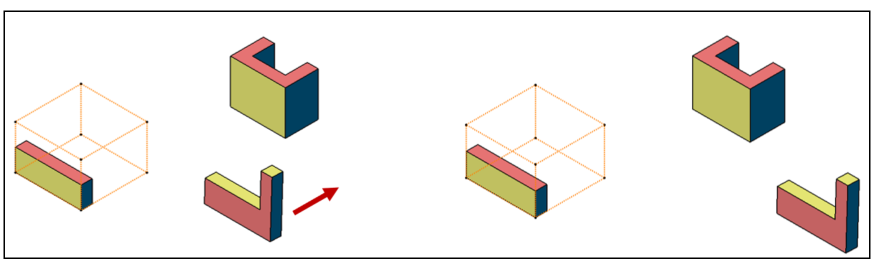


Figure 3. Translation of a component.

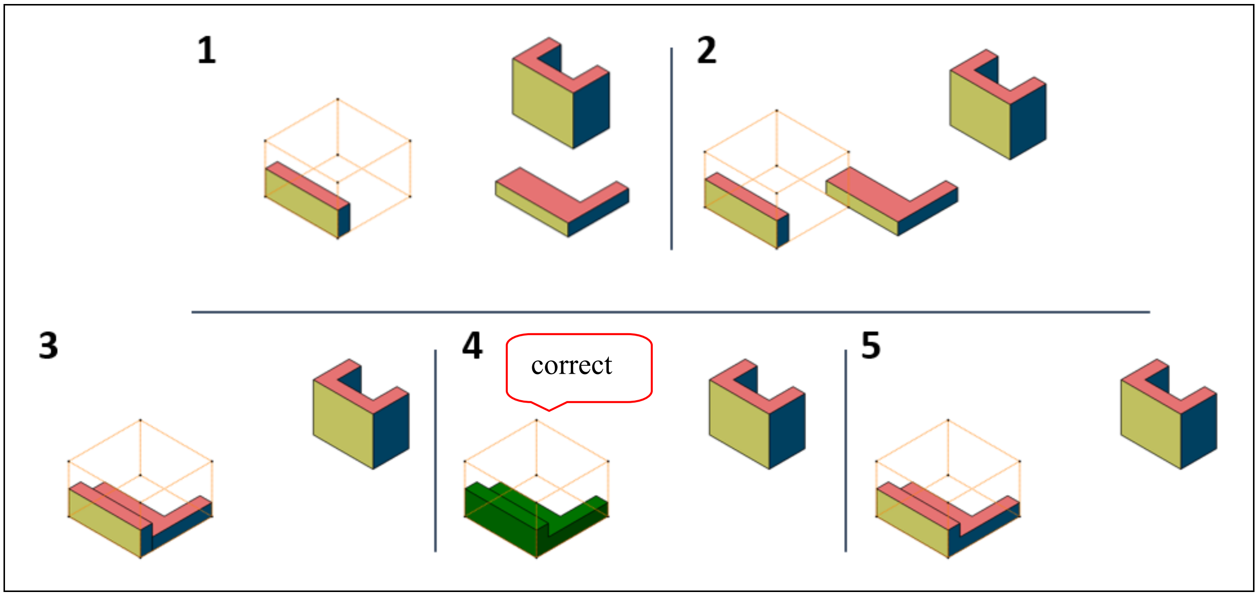


Figure 4. Assembly of a component into its correct position.

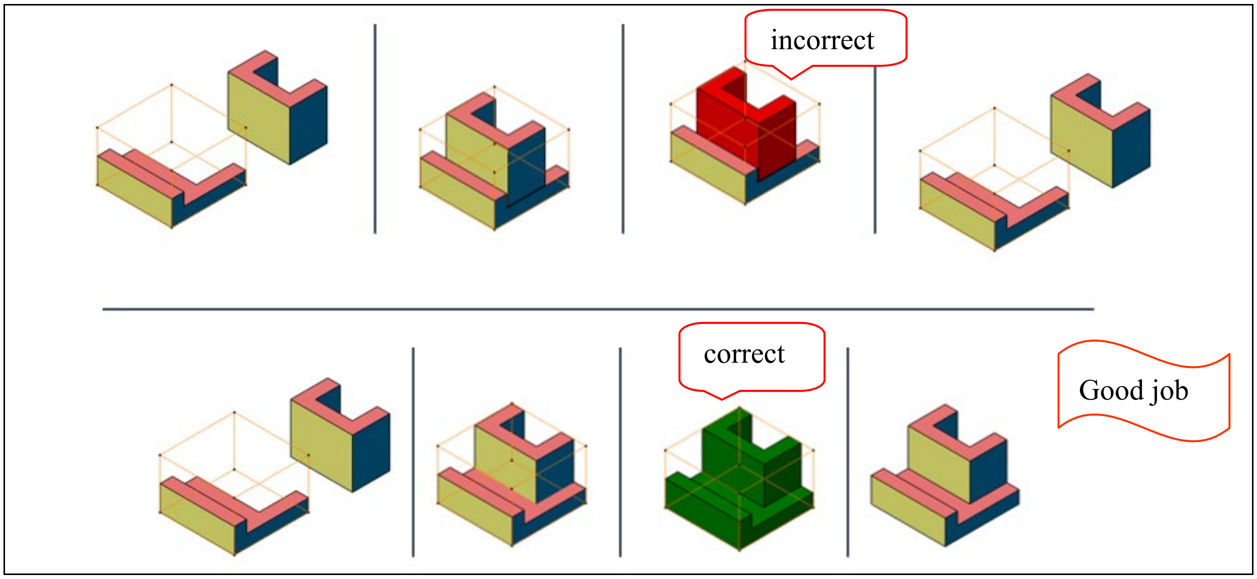


Figure 5. Active feedback displaying an incorrect placement (top in red) versus a correct placement (bottom in green).

To supplement the understanding of the manipulation of the 3D components, a series of video recordings for simultaneous viewing are developed. Each video is recorded according to the completion of each 3D component by emphasizing the relationship between the lines and surfaces in the given views and edited by Camtasia®. Figure 6 shows a screenshot of first component creation by analyzing the line and the surface relationship in the given views. Surfaces are color coded and labeled by letters, with the color consistent with the ones selected for the AR environment. Annotations and animations are added to highlight the analytical procedure.

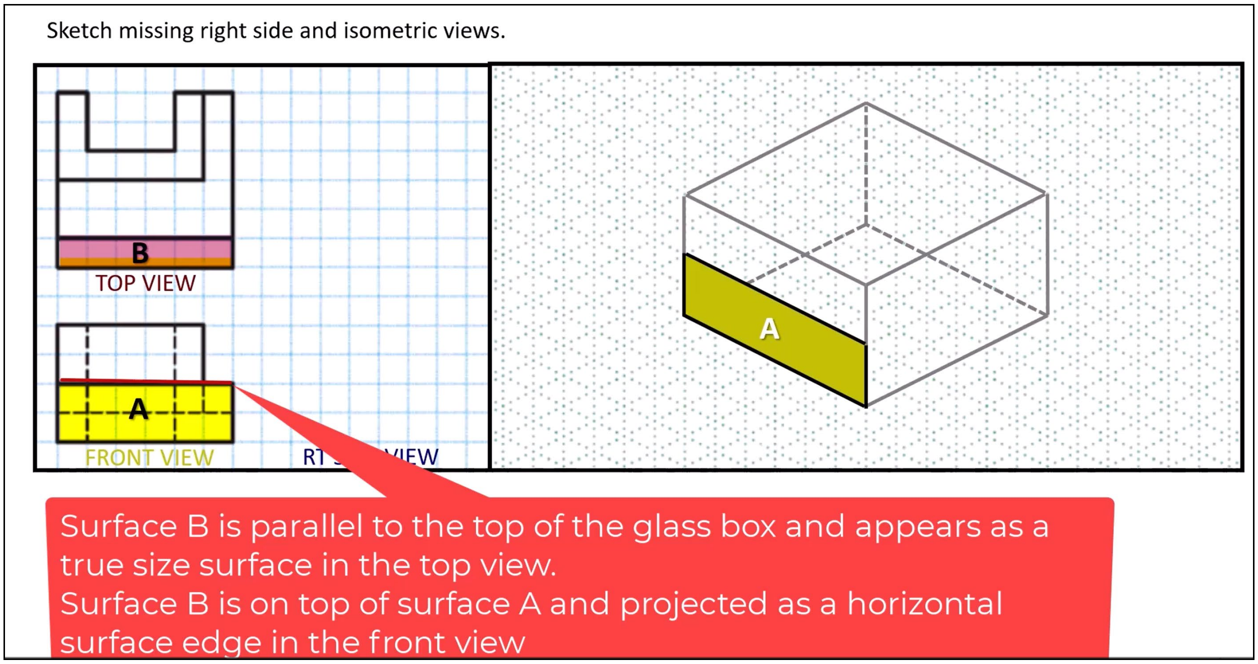


Figure 6. A screenshot of first component creation by analyzing the line and the surface relationship in the given views

Summary and Future Work

The baseline model is being developed in the SSTAR application. We aim to finish all models by the summer of 2024. The SSTAR will be tested in the engineering graphics course starting in the fall of 2024. Standard test instruments assessing spatial skills will be administered in the SSTAR sections and the non-SSTAR sections to collect baseline data and assess the success of the project.

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