Board 385: Spatial Skills with Augmented Reality: The Journey of Integration

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Introduction

Engineering graphics have shown to be an important component as part of the development and formation of engineers, considering the increase in Computer-aided Design (CAD) software usage in the engineering process. This usage has made spatial skills education essential for as such skills have shown to correlate to later success in an engineering career. However, research has shown that the current learning environment has not been conducive in learning spatial skills, especially for women, gender minorities, and socioeconomically disadvantaged students. This phenomenon can contribute to the stubbornly consistent pattern of low representation and participation of these minoritized students in engineering. Our project strives to address this practical gap by leveraging the technology of augmented reality/virtual reality (AR/VR) to create tools that can facilitate learning and development of spatial skills among these students. Specifically, we aim for such tools to help reduce cognitive load, provide more expansive visualization options for the students to develop their spatial skills, and create an enjoyable gamified learning environment. As this project is recently funded by the National Science Foundation (NSF), this poster, a follow-up from [blinded for review], will present the progress of the AR/VR integration of computer-aided design (CAD) models to create the aforementioned tools and share the lessons the team has learned thus far that can help with the tool development.

Literature Review

The need to enhance spatial skills learning environment aligns with scholarship that has demonstrated that spatial skills correlate success in STEM, and there is a gap that mirrors the phenomenon of low engineering participation among historically minoritized communities. For our project, we define spatial skills or spatial ability as abilities to mentally manipulate 2D and 3D objects that one can acquire through formal training [1], [2]. Research in the past decade has shown that spatial skills can predict STEM success among students, with findings showing that spatial skills can have a role in increasing the likelihood of obtaining advanced STEM degrees [3]. Sorby and colleagues have also found that improving spatial skills through intervention courses can impact the introductory STEM course grade performances of students who take the intervention courses [1]. Specifically, the study has shown such impact on grade performance in courses like Physics and Intro to Engineering, in addition to impact on STEM course GPAs [1]. However, results have also suggested from various studies that spatial skills training may not have a significant impact on student math grade courses, such as Pre-Calculus and Calculus [2], [4]. It has also been shown that there is evidence that shows spatial skill being a strong predictor of other STEM field performances, such as chemistry, physics, geology, medicine, and other fields [5]. Uttal and Cohen argued that spatial skill becomes less predictive as one moves toward gaining expertise in STEM knowledge, suggesting that spatial skills can help STEM beginners in succeeding learning STEM knowledge and performing in STEM courses [6]. The overall literature has shown the potential of improving student spatial skills, which can result in positive effects on students' performances in STEM courses.

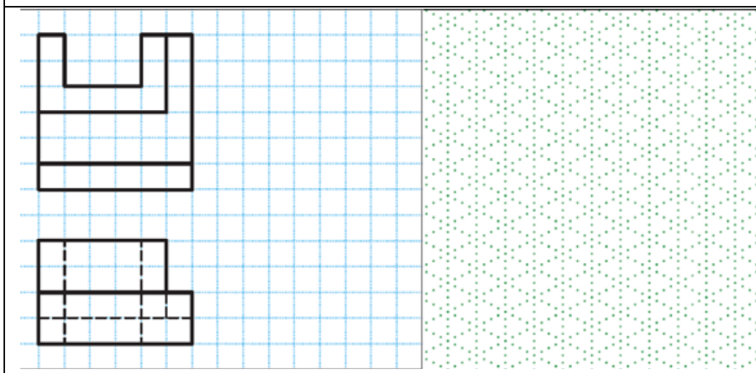
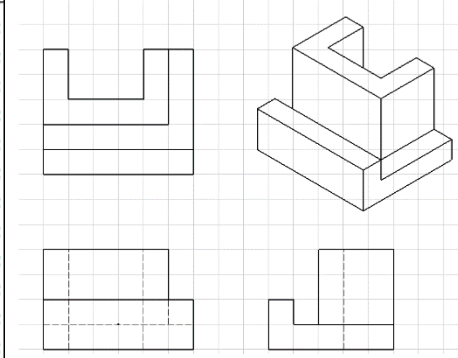
The positive effect of student spatial skills can subsequently aid student retention in engineering and STEM in general. Efforts to improve spatial skills should focus on acknowledging that minority differences are typically due to lack of prior exposure and spatial skills are malleable, meaning one can learn and attain the skills [7]. Various research has shown that there are persistent differences among students when it comes to spatial skills, with many arguing for improved learning environments due to previous lack of exposure to address the differences in spatial skills, which were found to be experiential rather than biological [2], [8], [9], [10], [11], [12], [13], [14]. In the seminal article about improving spatial skills and female student retention, [4] found that a specialized course to improve spatial skills among first-year engineering students improved spatial skill course grades for subsequent graphics courses and showed potential to remove another barrier toward retention of female engineering students. Such finding is supported by [12], where the research focuses on the spatial skills of students who identify as part of the Black community. The study argued that one should not look at these differences as inherent but stemmed from the inequality of educational opportunities and exposure to spatial skill education prior to enrolling in college. Research has also extensively discussed the relationships between the improvement of spatial skills and spatial training by summarizing existing research that shows "spatial training effects can transfer across different spatial abilities" [15, p. 160]. Overall, research has shown that there are efforts to improve spatial skills, which can help improve STEM outcomes. These have the potential to address the minority differences in spatial skills to improve retention among students who identify as part of the minoritized communities in STEM.

Along with teaching spatial skills, using computerized tools to support and supplement the learning and training of spatial skills among students has been widely documented. Engineering education research [16] found and documented that computer-based educational activities can support typical and traditional curricula to enhance children's development of spatial abilities. A study has shown the positive effect of using web-based games to teach visualization skills, with the students rating the games as useful [17]. However, the findings also show that such games should not substitute instructional personnel. Smartphones with touchscreen apps to sketch orthographic and isometric assignments have also been suggested to be beneficial to help students improve their spatial visualization skills as measured using the Purdue Spatial Visualization Test: Rotations [18]. Both tools were shown to provide in-time feedback based on the student performance to guide the students, especially if they did not answer or sketch correctly. This will become a key in our VR/AR integration as we develop the tools.

Integration Method and Results So Far

Currently, students in Engineering Graphics courses at a private, teaching-focused institution are assigned hand-drawing exercises, exemplified in Table 1, to enhance their spatial visualization skills. A significant challenge arises for students lacking a robust foundation in spatial skills, impeding their success in completing these exercises. The common issue lies in students struggling to utilize the relationships between lines and surfaces in given views to locate the same surfaces in isometric views or missing perspectives. Verbally explaining the orientation of surfaces on paper proves challenging, as it requires the ability to orient, visualize, and immerse oneself to discern the connections between surfaces.

Table 1. Current freehand sketching problem with its corresponding answer, as shown in [blinded for review].

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
	

Our project aims to aid these challenges by levering augmented reality/virtual reality (AR/VR) technology to develop supplemental teaching tools that facilitate the learning and enhancement of spatial skills among these students, with two components within the AR/VR tool: 1) The environment for object manipulation and 2) the supplemental guiding video. The overall concept involves students scanning the provided hand-drawing exercise using a designated tablet. Subsequently, students can engage with an interactive layout featuring individual components color-coded based on their orientation, along with the overall glass-box volume serving as a reference. Users are then tasked with manipulating these individual components to assemble them into a cohesive 3D model while being consistent with the provided orthographic projections.

Figure 1 illustrates the designed AR/VR environment for the specific example shown in Table 1. In this environment, students can choose from any available component to manipulate and place it onto the glass box volume. The components are characterized by three colors corresponding to the orientation of the views, carefully selected to be color-blind-friendly. Once the selected component is correctly positioned within the volume, the SSTAR will provide temporary feedback to confirm its accurate placement and corresponding gamification points will be awarded as an incentive. This feedback will be displayed temporarily, as preserving the original color-coding of the components is preferred.

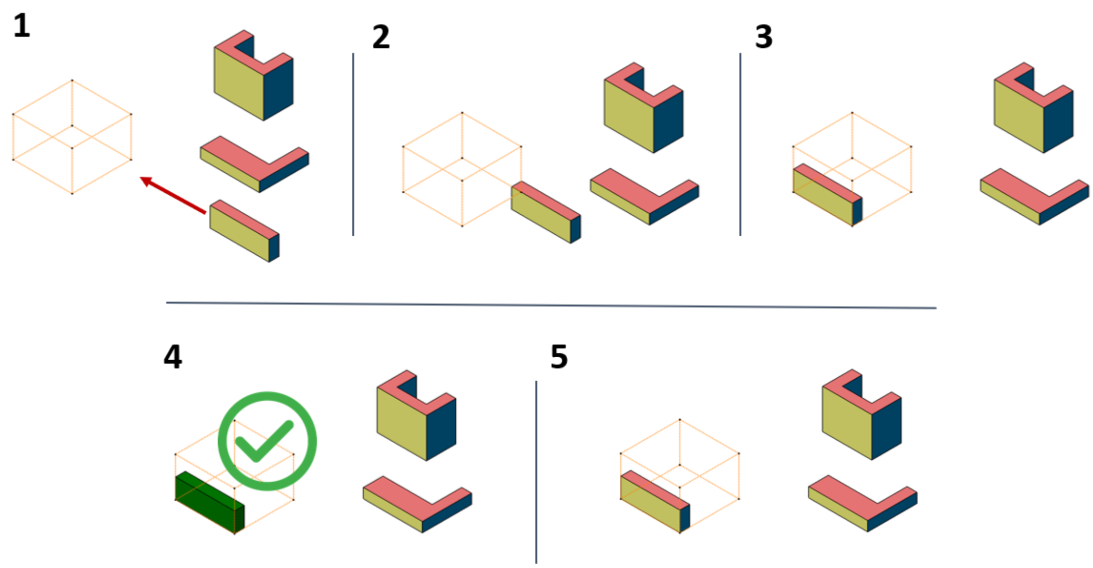


Figure 1. Component manipulation and placement onto the glass-box volume (1-3); temporary feedback to display correct placement (4); final layout before future manipulation (5). This is a slight variation of the environment as shown in [blinded for review].

Students have the option to either rotate the selected component around the X, Y, or Z directions or translate it to a different position. Figure 2 and Figure 3 illustrate the difference between rotation and translation. These manipulations are available for all components. Figure 4 demonstrates the repeatability of all previous features applied to 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 a corresponding callout. Students can accumulate gamification points as they correctly place components for each problem. Accumulated gamification points can motivate students to practice more and improve their final grade by a certain percentage as they successfully place components for each problem.

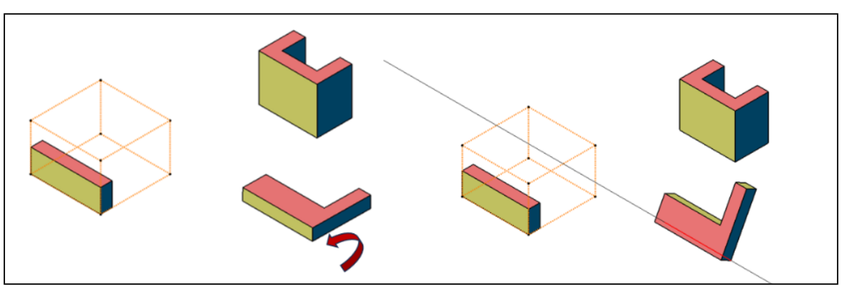


Figure 2. Rotation of a component, as illustrated in [blinded for review].

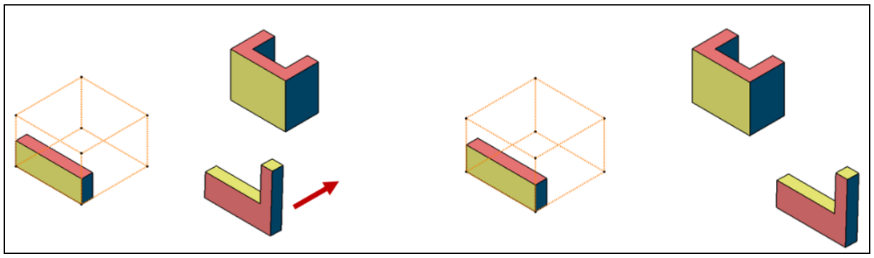


Figure 3. Translation of a component as illustrated in [blinded for review].

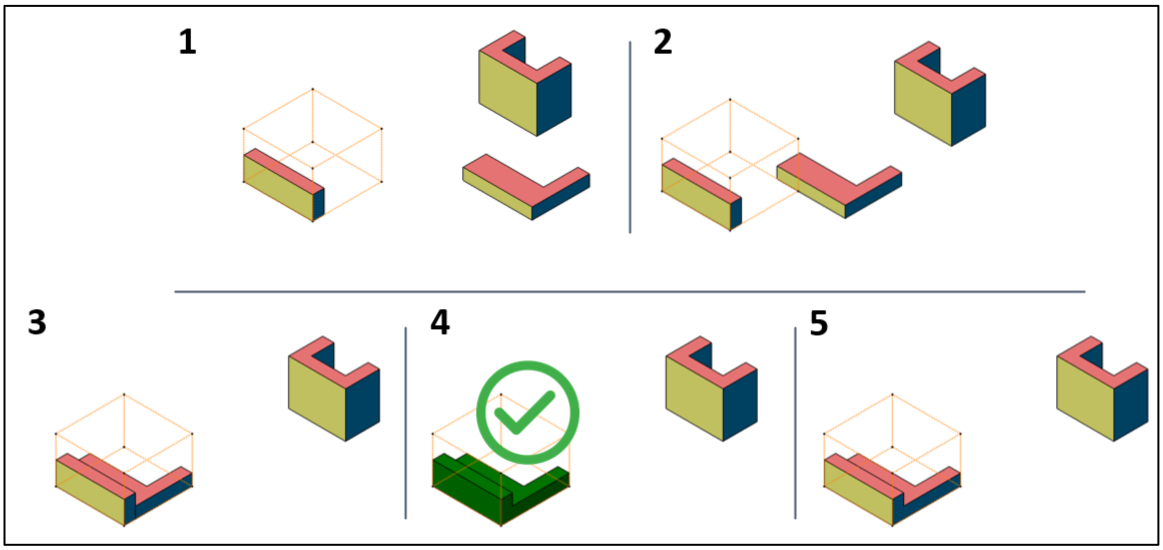


Figure 4. Assembly of a component into its correct position as illustrated in [blinded for review].

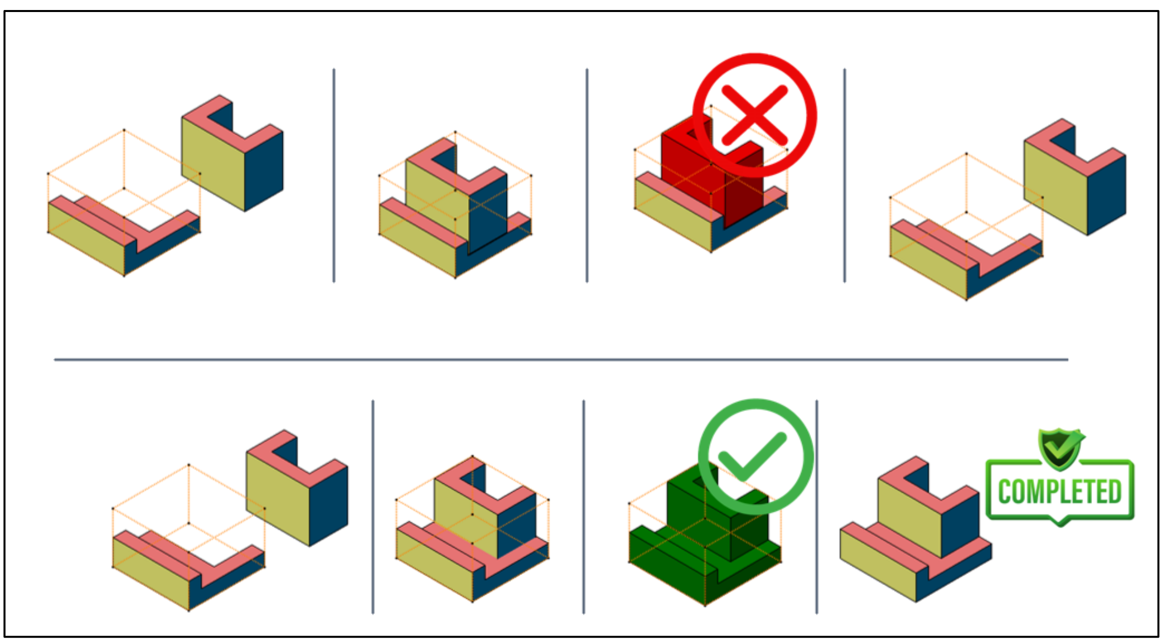


Figure 5. Active feedback displaying an incorrect placement (top in red) versus a correct placement (bottom in green), and the completion of the exercise. This is an improved version from [blinded for review]

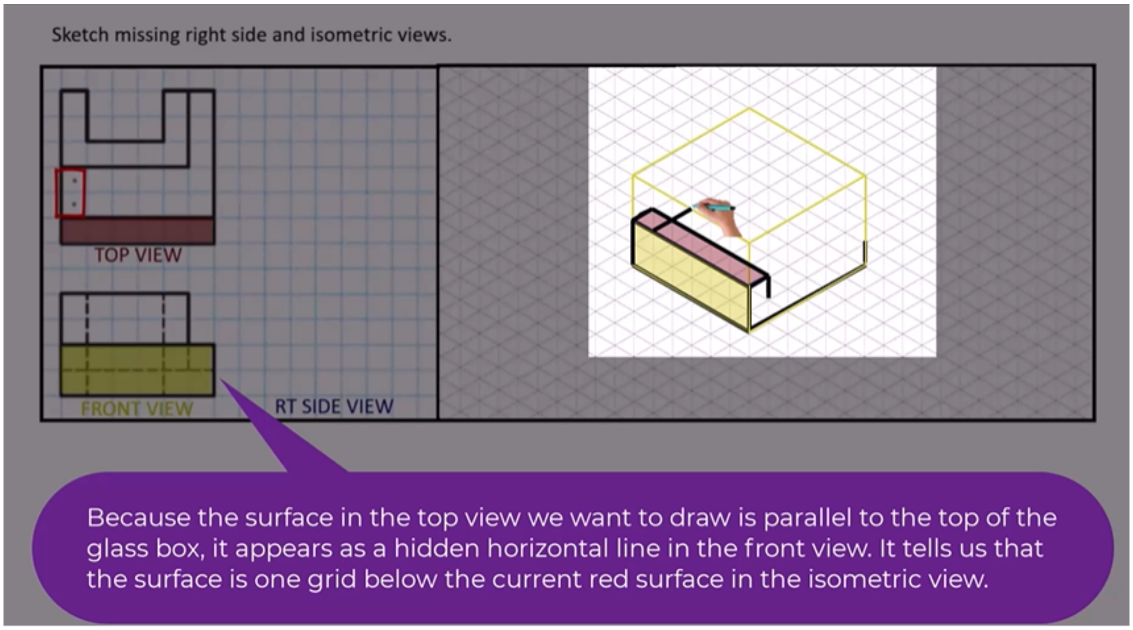


Figure 6. A screenshot depicting the creation of the second component by analyzing the representation of hidden lines in the Front View to the isometric and Top View, which is an updated view from the one presented in [blinded for review].

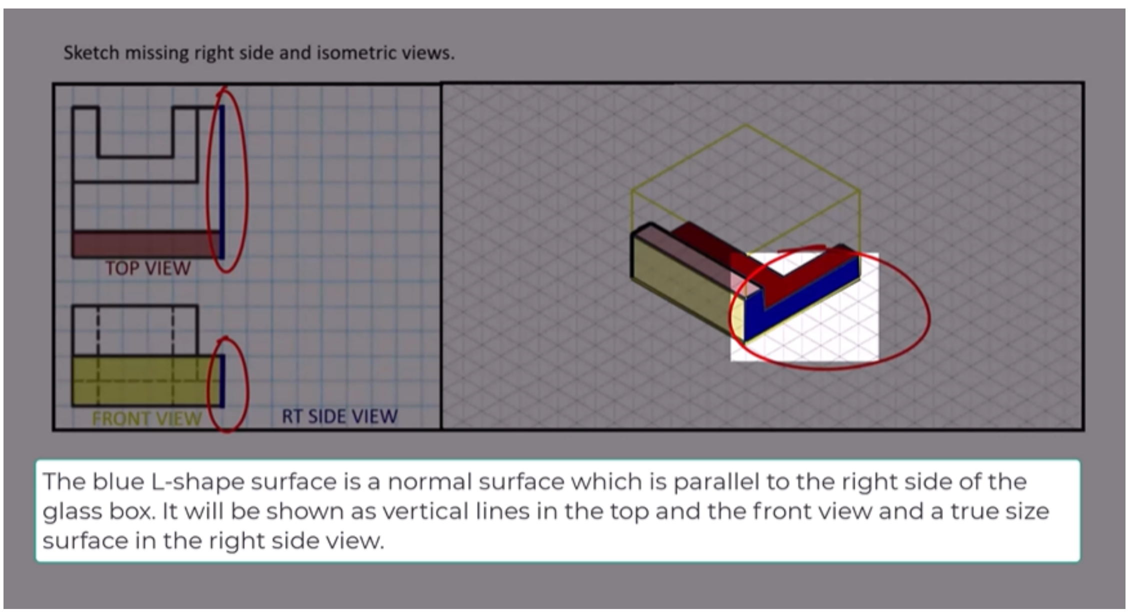


Figure 7. Concluding the second phase of the exercise by exemplifying the relationship between the surface in the Right-Side View to the Front and Top View, illustrated as a line.

To enhance the understanding of 3D component manipulation, a set of video recordings for simultaneous viewing is provided. Each video is recorded upon the completion of a 3D component by emphasizing the relationship between the lines and surfaces in the given views. Surfaces are color-coded and labeled by letters for perspective views (Top View, Front View, and Right-Side View). Annotations and animations are incorporated to underscore the analytical procedure. The images below illustrate the implementation of the supplemental videos and the intended design purpose for the specific phase in the exercise. Figure 8 below shows the first part of the integration with the Unity platform.

Another component of our tool is gamification. Gamification or gamified learning involves using elements of gaming design and development to promote enhanced learning experiences for the user [19]. The ultimate objective of gamification in such context is to make the learning process an enjoyable, fun-based learning experience. Unlike traditional exercises in spatial-skills curriculum that are more procedural, this based interactive learning tool allows students to explore, make mistakes, and learn by repetition. Users generally tend to actively participate in such learning activities, as they also assist students in exploratory learning where they are provided clues and incentivized for correct attempts. These approaches motivate students to learn despite mistakes and review and repeat exercises until they understand the materials thoroughly.

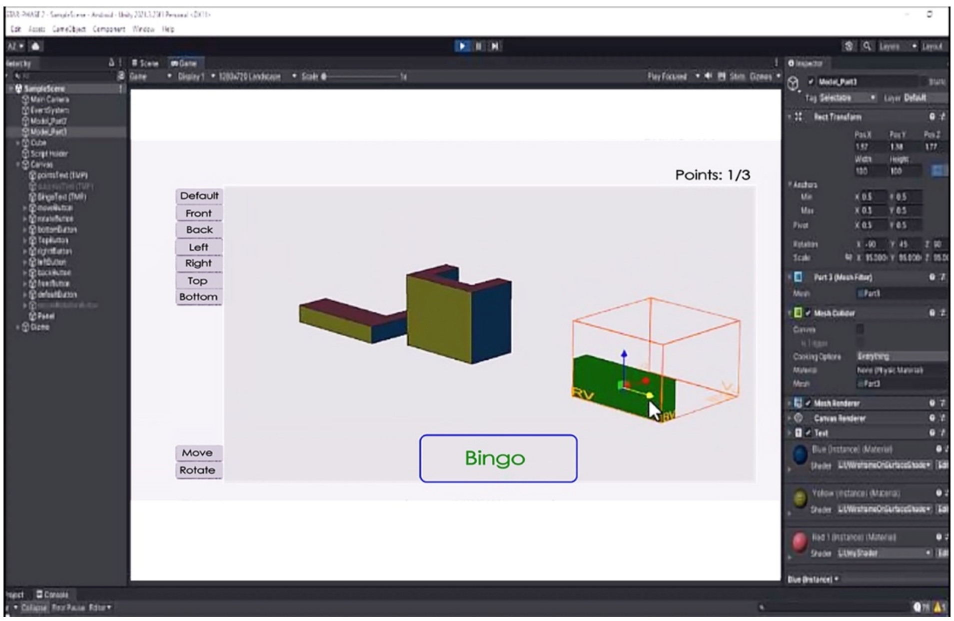


Figure 8. Programming the Gamified learning modules in Unity Environment for User Interaction

As the supplemental video dissects the process, one of its primary objectives is to pinpoint the gaps that students often encounter during the creation of various views. Figures 6 and 7 serve as notable examples illustrating common misconceptions among students regarding depth, hidden lines, and the connection between surfaces and lines.

This resource will enable students to delve deeper into each section of the part in the provided exercise. Literature in the Journal of Occupational Therapy Education exemplifies that students find supplemental videos to enhance their learning experience, due to students having "control over the pace of information delivery, the frequency of content delivery, and the environment in which they viewed the content" [20].

Another important consideration of the AR tool is to help students feel comfortable and confident with using the tool without needing them to go through a heavy cognitive load in learning how to use the tool. With accessibility in mind, we strive to produce a tool that does not require a significant learning curve to be able to use the tool. Currently, we are proposing to have students be able to scan a QR code to download the parts in the augmented reality environment so that they can immediately manipulate the parts using their phones, possibly providing a smooth transition into using the tool.

Lessons Learned so Far and Future Work

Through the integration process at this point, we discovered some challenges. First, the import of CATIA-based models into the Unity platform for integration. However, the process was performed successfully after several trials. Second, as we developed the supplemental videos, we found out that the videos can be created in a more targeted manner for in-time feedback while the students are manipulating the object to learn about the different parts of the object. The current supplemental videos provide a high-level view of the concepts, but they could be split into smaller chunks or more targeted concepts/misconceptions to help the students. For future work, our team is focusing on developing the baseline VR/AR tool on normal surfaces, as illustrated in this paper, the supplemental video, and the next integration of the environment and the video. We plan to pilot the tool in summer and fall classes this year.

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