A Feasibility Study of Spatial Cognition Assessment in Virtual Reality for Computer Aided Design Students

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Introduction

Research shows that cognitive functions are crucial components of mental processes and play a crucial role in our ability to perform a variety of tasks (e.g., [1], [2], [3]). In computer-aided design, cognitive functions such as perception, retention, visuospatial skills, etc. are relevant to using 2D drawings and 3D models in virtual reality (VR) environments. For example, the student must recognize and interpret a three-dimensional model from its orthogonal two-dimensional representations on a blueprint. Additionally, they must be able to store and recall information, which is essential in remembering prominent features of designs [4], which, in return, develops the ability to recognize objects and identify their features based on visual information known as visual gnosis [16]. These cognitive functions play a crucial role in our ability to understand and manipulate information within virtual reality environments, such as those used in computer-aided design. In contrast, the number of VR headsets is increasing [5] as more industries find value added positive impacts on their business activities. Therefore, a gamified custom-developed tool is needed to engage and motivate students as they are improving their spatial cognitive skills. Kuznetcova et al [6] report that Visuospatial thinking relate to the movement, location, and characteristics of objects and are integral components of both academic and general lifestyles. This study investigates whether a custom-built VR application can improve student visuospatial reasoning. In this regard, the proposed custom-developed VR tool is expected to provide a deeper understanding of 3D models and their features, which is the essential purpose of this experimental study.

Background

VR technology has shown potential in testing and improving the spatial cognition of students, particularly in Computer-Aided Design (CAD). Existing studies [1], [2], [3] show that VR-based CAD environments can provide an immersive and interactive experience that allows students to manipulate virtual objects and understand their spatial relationships [4][7]. For instance, research has found that 3D VR environments enhance students' spatial cognition skills by providing a more realistic representation of objects in space [2]. An experiment by the authors showed that participants trained in a 3D VR environment performed increased accuracy on a spatial cognition task than those trained in a 2D environment [8]. Furthermore, VR technology has been identified as an effective tool for testing and improving students' spatial cognition skills in CAD [9]. It is important to note that students' better understanding of complex spatial relationships and improving their 3D design skills early in college must be considered [1], [7], [9], [10]. As VR technology continues to advance, its use in CAD education will likely become more widespread (e.g.,[9], [16]). However, more research is needed to better understand the effectiveness of VR applications in enhancing students' spatial cognition skills. This study may contribute to the existing literature through the investigation into how the custom-built VR application impacts students' visuospatial reasoning. In this study, the research team collected qualitative and quantitative data from students, subsequently the team analyzed the data using independent sample t-Test and paired sample t-Test in IBM’s SPSS 22. The following sections will provide a detailed description of the methods, data collection, and analysis.

Methodology and Experimental Data

The ability to visualize 3D objects with their orthogonal views and manipulate those 3D parts is a cognitive skill that is vital to many STEM (Science, Technology, Engineering, and Mathematics) fields, especially those requiring work with computer-aided design (CAD) tools [11]. Research suggests that well-developed spatial skills of this type are critical to successfully advancing in engineering and many other fields [12]. These types of spatial skills involve visualizing 3D objects and perceiving their different orthogonal viewpoints if they were rotated in space. The study team developed a custom – constructed VR application for college-level students that are involved in 3D modeling classes. The students usually ask feature-related questions to better understand and plan their design intent. In this regard, the study team incorporated existing 3D models that are taught in Spring 2023 classes in the VR environment. Solidworks and Creo Parametric modeled part files were imported to Unity via 3D Studio Max to retain the accuracy of the 3D objects. Importing these parts directly to Unity via .stl file loses detailed representations of the models, hence why the intermediate software such as 3D Studio Max or Blender were used to accurately import these parts. Because this study involves students from Texas, the imported 3D parts needed to be represented in the gamified western style shooter game, where the students could relate to their culture.

The participating students answered spatial cognition questionnaire, where the students identified various representations of 3D models, based on their isometric views from 123tes.com. For pre-test study, the research team provided the proposed VR application, where they could see similar parts (not same) in isometric views, which they could walk around, run around, or pull closer to themselves to rotate and visualize different features of those models. In this regard, this study involved the introduction of a VR tool in an engineering graphics course, where freshmen/sophomore engineering students developed both 2D orthogonal and 3D isometric views of modeled parts. In the spring 2023 semester, a total number of ninety-two, with 80.43% (74) male and 19.57% (18) female college students from six different classes, taught by two different professors, with diverse socio-ethnic backgrounds, participated in the study as seen in Figure 1.

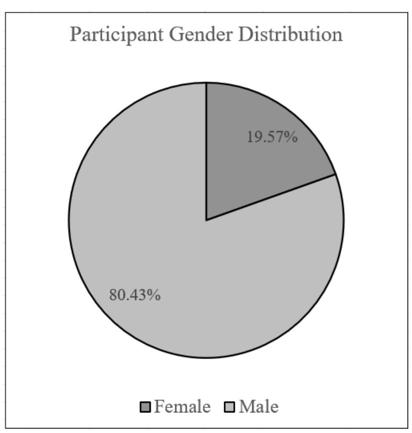

Figure 1. Participant Gender Distribution

The participants were categorized into three groups, where Group 1- Online (male = 46.74% and female = 11.96%), who completed their survey online, Group 2- In-Person VR (male = 18.48% and female = 5.43%), who participated in the study in person, and Group 3- Mixed Group (male = 15.22% and female = 2.17%), that received both Online and In-Person exposure to the study as seen in Figure 2. Figure 3 shows gender distribution for Online and In-Person VR groups only.

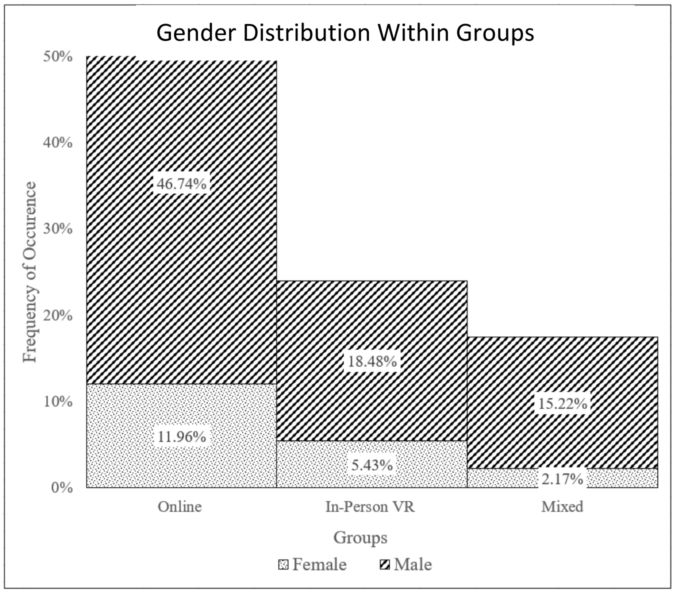

Figure 2. Gender Distribution of Groups

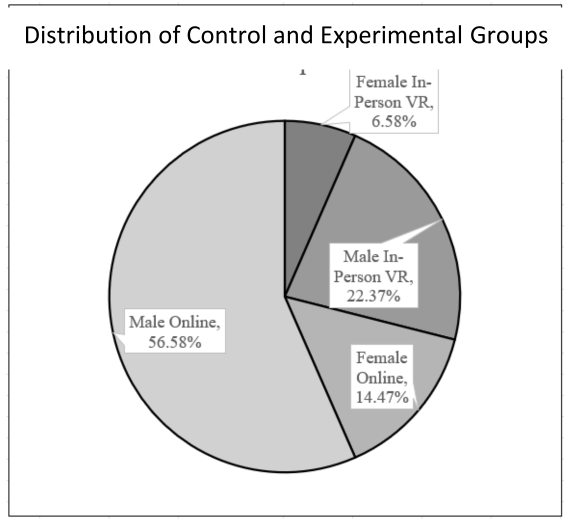

Figure 3. Distribution of Control and Experimental Groups

The researchers have studied approximately 970 students in the past 5 years from spatial reasoning tests. This data was incorporated into the Spring 2023 participants to increase the accuracy of statistical reports [13]. In spring 2023 four classes (Online group) completed a 10-question spatial reasoning test online (123test.com) with no prior experience in the VR, while the other two spring 2023 classes (In-Person VR group) participated in an immersive shooter-game style virtual environment to observe 3D parts and select/shoot the correct 2D orthogonal view representations provided in 10 questions as seen in Figure 4. To explore a western-shooter style spatial reasoning application in a VR environment both male and female students participated in a randomized fashion.

Figure 4. Testing the VR game environment

The control group (Online = 690), with no prior spatial cognition study exposure, received spatial reasoning questions from 123test.com and completed them individually, while the experimental group (In-Person VR = 280) received the Oculus Quest 2 headsets with the preloaded application as seen in Figures 4 & 5.

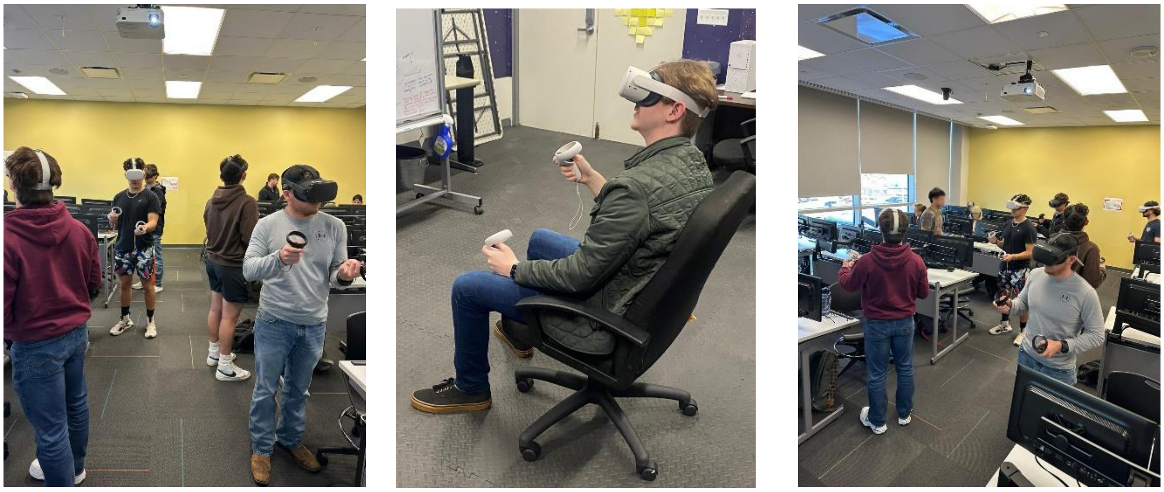

Figure 5. In-Person VR Participants

Data Analysis

An independent sample t-Test was conducted between the mean values of responses for groups: 1- Online and 2- In-Person VR participants. The control and experimental groups that participated in this study involved 690 and 280 participants, respectively, as shown in Table 1. The descriptive statistics table (Table 1) illustrates that the mean value for the In-Person VR group increased by .654 (from $\text{Mean}_{\text{online}}$ =5.789 to $\text{Mean}_{\text{In-Person VR}}$ =6.433) when the participants experienced the VR tool. The mean value for the In-Person group shows $\text{Mean}_{\text{In-Person VR}}$ = 6.433 and the mean value for the Mixed Group was $\text{Mean}_{\text{Mixed Group}}$ = 5.9375 there is a .495 difference between groups. The distribution curve (Figure 6) shows that most participants scored between 5 and 7.

Table 1. Descriptive Statistics (In Person VR vs Online)

Group Statistics					
Groups		N	Mean	Std. Deviation	Std. Error Mean
Scores	In Person VR	280.000	6.443	2.138	0.255
	Online Only	900.000	5.789	0.901	0.030

Two tailed t-Test shows that there is a significant difference between the two groups (p-value = 0.001<alpha level = 0.05) as illustrated in Table 2. With the 95% confidence interval, the data

suggested that introduction of a VR application significantly improves spatial cognition skills (Mean $_{\text{In-Person VR}}$ = 6.443 > Mean $_{\text{Online Only}}$ = 5.789) for 970 observations in this study.

Table 2. Independent Sample t-Test (In Person VR vs Online)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Scores	Equal variances assumed	320.808	0.000	5.072	968.000	0.000	0.654	0.129	0.401	0.907
	Equal variances not assumed			2.542	70.919	0.013	0.654	0.257	0.141	1.167

As the number of participants increased, the significance of using a VR tool in class occurred increased respectively. The team also explored how the VR tool impacted the spatial cognition skill of the same group. The Mixed group (Group 3, Figure 2) participated in the online spatial cognition test at the beginning of the week and in the In-Person VR experiment at the end of the same week. The normality distribution curve (Figure 6) shows that most participants scored between 5.6 with a standard deviation of 1.9 for 32 occurrences.

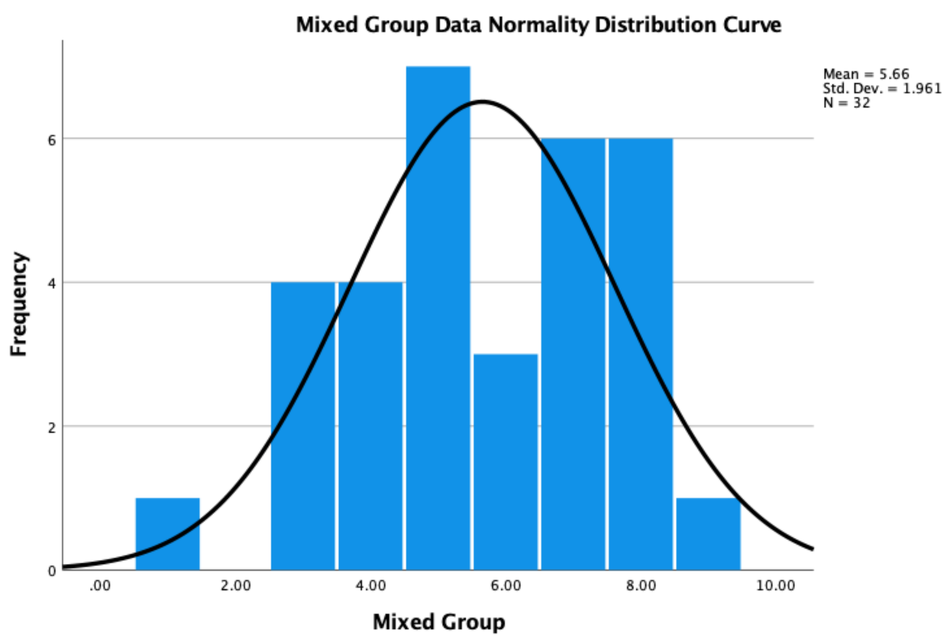

Figure 6. Distribution of scores for Mixed Online & VR group

Descriptives for paired sample t-Test (Table 3) shows 16 randomly selected participants in this study. The participating (Male = 14, Female = 2) students were from the same engineering graphics class and same instructor.

Table 3. Descriptives for Mixed Group

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Mixed VR	5.938	16	2.081	0.520
	Mixed Online	5.375	16	1.857	0.464

A paired sample t-Test (Table 4) shows that there was no significant difference p-value = 0.435 > alpha level = 0.05 between total number of 16 Mixed Online and Mixed VR participants. However, the mean value for Mixed Online Mean $_{\text{Mixed Online}}$ = 5.375 is less than Mixed VR Mean $_{\text{Mixed VR}}$ = 5.937 as shown in Table 3. This shows that the VR tool may improve spatial cognition skills for the same people that have been exposed to the test online.

Table 4. Paired Sample t-Test.

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	MixedVR – MixedOnline	0.563	2.804	0.701	-0.932	2.057	0.802	15	0.435

The availability and literacy of experiential technological tools, such as the current VR application, are directly correlated with student learning and success [14]. Overall, the investigators observed that cognitive reasoning [15] and interest in learning improved with the integration of VR tools in the classrooms. The professor’s comment regarding the experimental setup and the VR tool stated: " Integrating VR into our design class has sparked our students' imagination, fostered a more profound understanding of their creativity. We have observed that students could grasp complex spatial relationships and apply them to their designs."

Conclusion and Discussions

The purpose of this study was to investigate whether a virtual reality application impacts students’ spatial cognition skill. The study illustrated both independent sample t-Test and paired sample t-Test for randomly selected groups. The study results show that using innovative VR applications can enhance the understanding of 3D modeled parts and their orthogonal projections. While our study indicates that VR engagement can improve relevant skills, it was not the purpose of this study to explore the underlying mechanisms that drive these improvements. However, the immersive and interactive nature of the VR environment may allow for greater engagement and a deeper understanding of spatial relationships and concepts. Additionally, the ability to manipulate and explore objects in a 3D space may facilitate the development of mental rotation skills, which are crucial for spatial cognition. Future research could explore the specific cognitive processes involved in using VR applications for spatial cognition skill development by industry type to address our study's stated aims fully. In summary, this study provides evidence that innovative VR applications can positively enhance students' spatial cognition skills, which are crucial for success further supporting learning of computer-aided design skills.

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