ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE
Paper ID #37444

Using a theoretical model to understand how virtual reality influences engineering student's learning processes – A work in progress

Adurangba Victor Oje (Mr)

Victor Oje is a PhD Candidate in the College of Engineering. He is affiliated with the Engineering Education Transformations Institute. His research interest focuses on the pedagogical design of Virtual Reality (VR) environments and the use of learning principles to foster learning and engagement in VR environments. He is also interested in systematic review and meta-analysis research methodology. His research has implications on how instructional designers and instructors effectively use VR to enrich the learning experience within an engineering learning context.

Nathaniel Hunsu

Nathaniel Hunsu is currently an assistant professor of Engineering Education at the University of Georgia. He is affiliated with the Engineering Education Transformational Institute and the school of electrical and computer engineering at the university. He holds a PhD in Educational Psychology from Washington State University. His research interests are in learning and cognition, students' engagement in their learning contexts, and the assessment of learning and engagement in engineering classrooms. He conducts studies that examine student engagement and academic resilience in engineering education. He is currently the principal investigator on two NSF-funded projects. The first project examines factors that influence academic resilience among engineering students, while the other involves the development of a diagnostic tool to identify students' misconceptions in electrical engineering.

Dominik May (Dr.)

Dr. May is an Assistant Professor in the Engineering Education Transformations Institute. He researches online and intercultural engineering education. His primary research focus lies on the development, introduction, practical use, and educational value of online laboratories (remote, virtual, and cross-reality) and online experimentation in engineering instruction. In his work, he focuses on developing broader educational strategies for the design and use of online engineering equipment, putting these into practice and provide the evidence base for further development efforts. Moreover, Dr. May is developing instructional concepts to bring students into international study contexts so that they can experience intercultural collaboration and develop respective competences. Dr. May is President of the International Association of Online Engineering (IAOE), which is an international non-profit organization to encourage the wider development, distribution, and application of Online Engineering (OE) technologies and its influence on society. Furthermore, he serves as Editor-in-Chief for the International Journal of Emerging Technologies in Learning (iJET) intending to promote the interdisciplinary discussion of engineers, educators, and engineering education researchers around technology, instruction, and research. Dr. May has organized several international conferences in the Engineering Education Research field. He is currently program co-chair and international program committee member for the annual International Conference on Remote Engineering and Virtual Instrumentation (REV) and served as a special session committee member for the Experiment@ International Conference Series (exp.at).

Robert A Baffour (Dr.)

Using a theoretical framework to understand how virtual reality influences engineering students' learning processes

Abstract

In this work-in-progress, we conducted a study to test the validity of a previously proposed framework on the relationship between some salient Virtual Reality (VR) variables, students' psychological presence and learning experiences in a desktop VR-based learning activity for civil engineering students. Participants were 63 undergraduate students enrolled in an engineering class who interacted with a desktop VR application for a land-surveying activity. Reliability analysis showed that the internal consistency reliability for the constructs were high. Additionally, we observed positive and significant correlations between VR attributes, presence, and active learning. Furthermore, we found that some VR attributes significantly predicted active learning. We hope that the findings of the study contribute to the research evidence on aspects of VR that are most salient in fostering highly engaging learning experiences and beneficial learning outcomes for engineering students. Additionally, we seek to advance theory-driven VR research in the design and development of VR applications for engineering education.

1.0 Introduction

There has been a surge of interest in the use of educational Virtual Reality (VR) technology for engineering instruction in recent years. Educational VRs enable students to experience real-world learning activities in a simulated and safe environment [1]. Engineering instructors can facilitate practical learning and students can practice laboratory procedures and observe otherwise abstract concepts in a safe setting with little concern about the cost-related inhibitions that accompany the traditional instructional laboratory in engineering. Educational VRs are also employed in the classroom to facilitate experiential learning [2]. Students could, for example, engage in *hands-on learning* activities like manipulating virtual objects and engineering instruments. Additionally, students could observe and learn cause-and-effect relationships between engineering phenomena and even interact with engineering ideas or equipment in virtual space by modifying variables and recording observations. Some prior research has suggested that educational VR environments can support experiential learning of diverse engineering concepts [3, 4]. Furthermore, the study by Alhalabi [5] indicated that educational VR may be used in an engineering education context to facilitate learning and promote better students' performance relative to the traditional instructional approach to teaching certain engineering concepts. Other studies have examined learning benefits from VR simulations and found a significant effects on cognitive [6, 7] and non-cognitive outcomes [8, 9].

As a result of the increasing interest in educational VR in engineering education, there has been a commensurate increase in research efforts that examine the educational affordances of instructional VR. However, most current VR research in engineering education has concentrated on usability studies of instructional VR. While usability studies are commendable, there is an urgent need for studies that explore the affordances of VR for learning in engineering contexts, guided by proven theories of motivation and learning in extant educational research. Because many existing VR studies in engineering are not rooted in educational theories, we lack an explanatory and predictive framework for deconstructing how instructional VR can facilitate positive cognitive and non-cognitive outcomes in engineering classrooms.

Because much of VR research in engineering education focuses on the technological design of VR for engineering instruction, we are less informed about how VR environments can be used to support meaningful engineering learning experiences. Further, because VR for instructional usage is recent, only a few theoretical models that explore how VR facilitates positive learning outcomes have been proposed [10-12]. A few studies that sought to validate these models have been reported in the learning sciences and educational technology research literature. However, there has been scarce research activity to determine the validity of these models for understanding the efficacy of instructional VR within engineering education research.

1.1 Study Objectives: To address this gap in engineering education instructional VR literature, this study investigates a recently proposed instructional VR in an engineering education context. The study examines the relationships between certain features of an instructional VR environment in an active learning context. The model of interest is discussed and outlined in the next section.

2. Theoretical frameworks to describe learning from VR.

With the proliferation of VR for instructional use, some scholars in the learning sciences have proposed theoretical models to explain how VR-based learning proffers educational benefits [10, 13, 14]. For example Lee et al. [10] proposed a model that describes the inter-relationship between the features of instructional VR environment (e.g., representational fidelity and immediacy of control), (usability experience e.g., perceived usefulness and perceived ease of use), psychological factors (e.g., presence, motivation, perceptions of cognitive benefits, and reflective thinking), learner traits (e.g., spatial abilities and learning styles), and learning outcomes (including performance achievement, perceived learning effectiveness, and satisfaction).

Lee's conceptual framework highlighted causal links between VR features and psychological factors that are germane to fostering meaningful learning in instructional VR environments. The model is illustrated below with links showing direct effects and a dashed line showing indirect effects of variables on the outcomes they proposed. In their conceptual framework, Lee and colleagues predicted that the effect of design features of the VR environment on learning outcomes was mediated by usability and psychological factors of learning (e.g., presence, motivation, cognitive benefits, and reflective thinking).

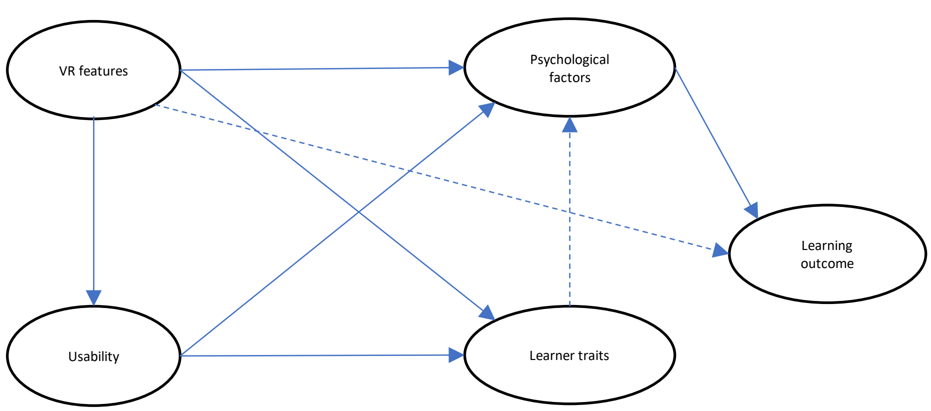

Fig 1. Conceptual framework of VR variables, usability, psychological factors, learner traits and learning outcomes as described by Lee and colleagues

In this current study, we explore the causal relationships between elements of Lee et al.'s conceptual framework to examine how well some of the variables of VR features and psychological factors proposed by Lee and co are relevant to a VR-based learning situation in an engineering learning context. This research effort could inform best practices and enlighten instructional designers and educators on design features that are salient in promoting the effectiveness of desktop VR-based instructions in engineering education.

3. Methods.

3.1 Participants and Data Collection procedure

Participants consisted of 63 undergraduate civil engineering students who enrolled in a land-surveying course at a public research institution in the United States. Students were assigned to two lab sessions as part of the lab activity, during which they interacted with a desktop VR (Refer to Fig. 2) application for a land-surveying designed by a VR design team in the institution. Following the lab activity, participants were asked to respond to survey items about their experience in the VR environment. The survey items were adapted from prior research and were rated on a seven-point Likert Scale that ranging from 1 (being "Strongly disagree") to 7 (being "Strongly agree").

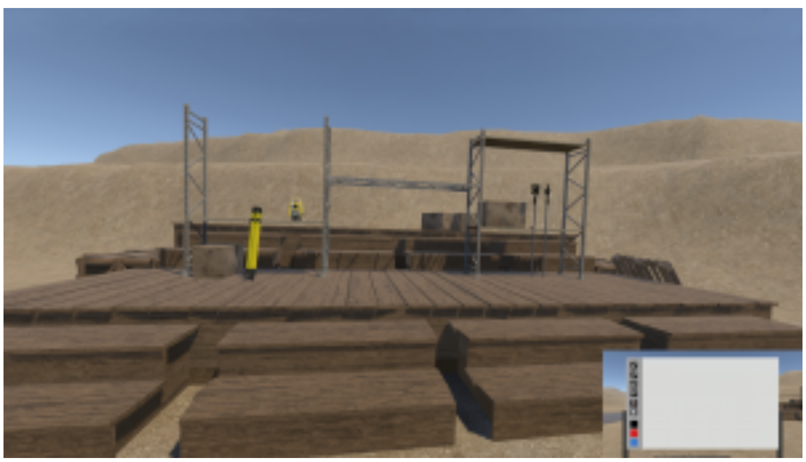

Fig 2. A land-surveying VR-based simulation

3. 2 Materials

The questionnaire used in this study included items adapted from Lee et al. [10]. Two constructs related to educational VR technology's attributes: representational fidelity and immediacy of control with three items adapted from. *Representational fidelity* items assessed how the degree of realism provided by the 3D-images of the VR aided their understanding, e.g., the realism of the 3D-images motivates me to learn, the realism of the 3-D enhances my understanding. Additionally, four items adapted from Lee et al. [10] were used to measure *immediacy of control*. Items assessed the ability to manipulate the objects or view positions in the VR application, e.g., the ability to manipulate the objects within the virtual environment makes learning more motivating and interesting.

Six items derived from Sutcliffe, et al. [15] were used to assess *presence*. These items assessed the subjective experience of 'being involved' with the VR application, e.g., I was involved in the experimental task to the extent that I lost track of time, I was involved in the virtual environment experience. Furthermore, five items derived from Lee et al. [10] were used to measure *control and active learning*. These items assessed students' control over their learning, their engagement in the learning activity, and their active processing of the learning activity e.g., this type of virtual reality allows me to have more control over my learning, this type of virtual reality helps to get me engaged in the learning activity. Demographic items such as age, gender, and college classification were included in the survey.

4. Data Analysis and Results

All analyses were conducted in IBM SPSS version 25.0. First, we carried out preliminary analysis to ascertain the internal consistency of the constructs used in this study. Secondly, we used Pearson correlation analysis to determine the strength and direction of relationships between VR features, presence, and active learning when using the VR application. Finally, we used regression analysis to establish the relative contribution of these correlations to predicting active learning when learning with engineering VR applications. Cronbach alpha values greater than or equal to 0.70 suggest acceptable reliability estimates [16].

4.1 Internal Consistency Evidence: The variables examined in the study exceeded the acceptable reliability value of Cronbach’s alpha. The internal consistency reliability of the VR feature variables, i.e., representational fidelity and immediacy of control were 0.84 and 0.91, respectively. The internal consistency Cronbach’s alpha for presence was 0.79, while that of the control and active learning constructs had an internal consistency Cronbach’s alpha of 0.89. The descriptive statistics and internal consistency of all constructs are shown in Table 1.

Table 1.

Descriptive statistics and reliability coefficients for the variables.

Variables of interest	Category	*M*	*SD*	Cronbach α
Representational Fidelity	VR features	4.49	1.32	0.91
Immediacy of control		4.38	1.20	0.84
Presence	Psychological factor	4.67	1.50	0.79
Control and Active Learning	Student learning	4.89	1.25	0.89

4.2 Correlational Analysis: We examined correlations between VR features (i.e., representational fidelity and immediacy of control), and students' psychological presence and active learning. Positive and significant relationship were identified between the VR attributes, presence, and active learning. Immediacy of control was positively related to representational fidelity ($r = 0.78$). Additionally, presence was significantly correlated with two VR features – representational fidelity and immediacy of control (r = 0.72, 0.81 respectively). Finally, active learning was found to be associated with VR features and psychological presence (r = 0.71 ~ 0.8). Refer to Table 2.

Table 2.

Correlation coefficients among variables

	Variables	1	2	3	4
1	Representational fidelity	1	.78**	.72**	.71**
2	Immediacy of control		1	.81**	.87**
3	Presence			1	.82**
4	Active learning				1

*Note. **<.05*

4.3 Regression Analysis: Finally, we used regression analysis to examine the relative contributions of two variables of VR environment features, psychological presence, and active learning. The first model represented representational fidelity and immediacy of control (both VR attributes), but the second model incorporated students' psychological involvement (presence) when learning via the VR application. Overall, the model explained 80 % of the variance in the outcome variable. The first regression model revealed that immediacy of control was the only significant predictor of active learning (β = 0.82, p < .001). Representational fidelity was not a significant antecedent to active learning. The first model explained 76% of the variance in active learning outcome $R^2 = .76, Adj. R^2 = .75$). Presence was included as a predictor of active learning in the second model. The second model revealed that the presence and immediacy of control strongly predicted active learning and accounted for almost 80% of the variance in the outcome measure, ($R^2 = .80, Adj. R^2 = .79$). Immediacy of control was a significant predictor of active learning ($\beta = 0.61, t = 5.34, p < .01$). Additionally, it was observed that presence was a significant predictor of active learning ($\beta = 0.35, t = 3.38, p < .001$).

5. Discussions and Scholarly Implications

These findings demonstrate that the relationships between VR features and presence are congruent with established theoretical propositions in the educational VR literature. Prior studies have indicated that the degree of immersion or realism provided by a VR environment influences presence. Dalgarno [17], for example, argued that presence is dependent on the rendering fidelity of a VR environment. A meta-analysis of 115 effect sizes from 83 studies indicates that there is a positive correlation between the degree of realism provided by a VR and student's presence [14]. Makransky, et al. [18] investigated the effect of the degree of immersion in a VR environment on presence when using VR to learn biological concepts. Their findings suggest that more immersive VRs affords a greater sense of presence.

Our findings indicate that building VR applications with more realistic three-dimensional (3D) graphics may have a positive effect on the psychological involvement of learners in VR activities. The development of instructional VR applications that have more realistic 3D visuals of engineering content may have a greater likelihood of increasing student's psychological engagement with VR-based instructional activities. Additionally, the positive and significant relationship between immediacy of control and presence suggests that VR applications might have a positive psychological effect on users' cognitive involvement with their activity when they are able to manipulate and control objects in a VR environment. These findings may have relevance for instructional designers who wish to create VR programs that are more realistic and interactive. No doubt, enhancing student's sense of presence may inspire them to be cognitively active during the learning process.

The regression analysis suggested that immediacy of control and presence explained 79% of the variance in students' active learning during the VR activity. These findings suggest that the ability to manipulate objects in educational VR environments may increase cognitive engagement with the instructional content, while merely introducing learners to a VR-based learning opportunity may not be sufficient. Invariably, it may be crucial that effective instructional VR environments are designed to facilitate more meaningful learner-content interaction.

In our study, an intriguing finding, or lack thereof, was that representational fidelity was not a major predictor of active learning. The results corroborate prior research demonstrating that immersion level does not always correlate with higher learning outcomes [18, 19]. Some studies have also reported that learning via low-immersive media produces superior learning outcomes compared to learning via high-immersive media [20-22]. This would indicate that immersion may not always lead to positive learning outcomes. Prior studies have indicated that immersion is important for engendering presence, which implies that immersion is an important VR feature. Nonetheless, our study seems to indicate that interactivity may be more salient in fostering engaging learning experiences for engineering students. Perhaps there are boundary conditions of the effects of immersion on positive learning outcomes that need to be further explored in future studies. In practice, our findings might imply that educators and VR developers may prioritize VR interactivity features over immersion or realism.

6. Conclusion and Future Directions

Our study provides preliminary evidence for the characteristics of VR that may be important for fostering highly engaging learning experiences and positive learning outcomes in engineering education. The study examined elements of a previously established theoretical framework in the literature regarding the relevant variables associated with the process of learning in VR. One limitation of this study was that we examined the relationships between these factors using a portion of the constructs (four) proposed by Lee et al. In the future, we will incorporate additional constructs related to the processes of learning through VR. Future studies will also include examining how students' interactions with and engagement in VR-based instruction stimulate motivation and satisfaction with their learning experience. Such studies may inspire the design of beneficial VR-based learning in engineering education contexts.

Table 3.

Summary of Hierarchical Regression Analysis: Using VR features, psychological factors as predictors of Active Learning

Model	Variables	Unstandardized Coefficients B	*SE*	Standardized Coefficients β	*t*	*Sig.*	R2	Adjusted R2	ΔR2
1	Representational fidelity	0.86	0.56	0.61	0.59	0.55	0.76	0.75	
	Immediacy of control	0.79	0.09	0.82	8.01	0.00**			
2	Representational fidelity	-0.02	0.96	-0.023	-0.23	0.82	0.80	0.79	0.40**
	Immediacy of control	5.88	0.11	0.61	5.34	0.00**			
	Presence	0.33	0.09	0.35	3.38	0.00***			

Note. ***<.01 ***<.0*

References

[1] L. Freina and M. Ott, "A Literature Review on Immersive Virtual Reality in Education: State Of The Art and Perspectives," *eLearning & Software for Education,* no. 1, 2015.

[2] J. Fromm, J. Radianti, C. Wehking, S. Stieglitz, T. A. Majchrzak, and J. vom Brocke, "More than experience?-On the unique opportunities of virtual reality to afford a holistic experiential learning cycle," *The Internet and Higher Education,* vol. 50, p. 100804, 2021.

[3] W. Huang and R. D. Roscoe, "Head-mounted display-based virtual reality systems in engineering education: A review of recent research," *Computer Applications in Engineering Education,* https://doi.org/10.1002/cae.22393 vol. n/a, no. n/a, 2021/02/13 2021, doi: https://doi.org/10.1002/cae.22393.

[4] D. Kaminska *et al.*, "Virtual Reality-Based Training: Case Study in Mechatronics," *Technology Knowledge and Learning,* vol. 26, no. 4, pp. 1043-1059, Dec 2021, doi: 10.1007/s10758-020-09469-z.

[5] W. S. Alhalabi, "Virtual reality systems enhance students achievements in engineering education," *Behaviour and Information Technology,* vol. 35, no. 11, pp. 919-925, 2016, doi: 10.1080/0144929X.2016.1212931.

[6] M. T. Bonde *et al.*, "Improving biotech education through gamified laboratory simulations," *Nature biotechnology,* vol. 32, no. 7, pp. 694-697, 2014.

[7] E. A.-L. Lee and K. W. Wong, "Learning with desktop virtual reality: Low spatial ability learners are more positively affected," *Computers & Education,* vol. 79, pp. 49-58, 2014.

[8] M. Seifan, N. Robertson, and A. Berenjian, "Use of virtual learning to increase key laboratory skills and essential non-cognitive characteristics," *Education for Chemical Engineers,* vol. 33, pp. 66-75, 2020.

[9] M. Thisgaard and G. Makransky, "Virtual learning simulations in high school: Effects on cognitive and non-cognitive outcomes and implications on the development of STEM academic and career choice," *Frontiers in psychology,* vol. 8, p. 805, 2017.

[10] E. Ai-Lim Lee, K. W. Wong, and C. C. Fung, "How does desktop virtual reality enhance learning outcomes? A structural equation modeling approach," *Computers & Education,* vol. 55, no. 4, pp. 1424-1442, 2010/12/01/ 2010, doi: https://doi.org/10.1016/j.compedu.2010.06.006.

[11] M. C. Salzman, C. Dede, R. B. Loftin, and J. Chen, "A Model for Understanding How Virtual Reality Aids Complex Conceptual Learning," *PRESENCE: Teleoperators & Virtual Environments,* Article vol. 8, no. 3, pp. 293-316, 06// 1999, doi: 10.1162/105474699566242.

[12] G. Makransky and G. B. Petersen, "The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive Virtual Reality," *Educational Psychology Review,* 2021/01/06 2021, doi: 10.1007/s10648-020-09586-2.

[13] L. Fung-Chun *et al.*, "A virtual reality application for distance learning of Taiwan stream erosion in Geosciences," in *International Conference on Computers in Education, 2002. Proceedings.*, 2002: IEEE, pp. 1156-1160.

[14] J.-H. Kim, S.-T. Park, H. Lee, K.-C. Yuk, and H. Lee, "Virtual reality simulations in physics education," *Interactive Multimedia Electronic Journal of Computer-Enhanced Learning,* vol. 3, no. 2, pp. 1-7, 2001.

[15] A. Sutcliffe, B. Gault, and J.-E. Shin, "Presence, memory and interaction in virtual environments," *International Journal of Human-Computer Studies,* vol. 62, no. 3, pp. 307-327, 2005.

[16] J. F. Hair, W. C. Black, B. J. Babin, R. E. Anderson, and R. L. Tatham, *Multivariate data analysis* (no. 3). Prentice hall Upper Saddle River, NJ, 1998.

[17] B. Dalgarno, "The potential of 3D virtual learning environments: A constructivist analysis," *Electronic Journal of Instructional Science and Technology,* vol. 5, no. 2, pp. 3-6, 2002.

[18] G. Makransky, T. S. Terkildsen, and R. E. Mayer, "Adding immersive virtual reality to a science lab simulation causes more presence but less learning," *Learning and Instruction,* vol. 60, pp. 225-236, 2019, doi: 10.1016/j.learninstruc.2017.12.007.

[19] O. A. Meyer, M. K. Omdahl, and G. Makransky, "Investigating the effect of pre-training when learning through immersive virtual reality and video: A media and methods experiment," *Computers & Education,* vol. 140, p. 103603, 2019/10/01/ 2019, doi: https://doi.org/10.1016/j.compedu.2019.103603.

[20] R. Moreno and R. E. Mayer. (2002) Learning Science in Virtual Reality Multimedia Environments: Role of Methods and Media. [Periodical]. 598-610. Available: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,shib&db=edsbl&AN=RN119301075&site=eds-live&custid=uga1

[21] J. Parong and R. E. Mayer, "Learning science in immersive virtual reality," *Journal of Educational Psychology,* vol. 110, no. 6, p. 785, 2018.

[22] J. Parong and R. E. Mayer, "Learning about history in immersive virtual reality: does immersion facilitate learning?," *Educational Technology Research and Development,* vol. 69, no. 3, pp. 1433-1451, 2021/06/01 2021, doi: 10.1007/s11423-021-09999-y.

Appendix

Description and Sample of Items used in this study

Representation fidelity: Degree of realism provided by the 3D-images of the VR aided their understanding.

1. The realism of the 3-D images motivates me to learn
2. The realism of the 3-D images helps to enhance my understanding.

Immediacy of control: Ability to manipulate the objects or view positions in the VR application.

1. The ability to change the view positions of the 3-D objects allow me to learn better
2. The ability to manipulate the objects in real time helps to enhance my understanding.

Presence: Subjective experience of involvement with the VR environment

1. I was involved in the virtual environment experience
2. My interaction with the simulation environment seemed natural

Control/Active learning: Psychological state of active processing, engagement and control when learning from the VR application.

1. This type of virtual reality helps me to have a better overview of the content learned
2. This type of virtual reality allows me to have more control over my learning

Note. Full survey items are in [6], [11]