Enhancing Engineering Education: Efficacy of a Virtual Classroom on Learning Basic Indoor Thermal Environment Engineering Concept

Cynthia Hou, The Hong Kong Polytechnic University, Hong Kong SAR

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Abstract
This study evaluates the effectiveness of a virtual classroom designed for building service engineering students, focusing particularly on Fanger's thermal comfort model. Traditional teaching methods often fail to fully engage students in complex engineering concepts; thus, this virtual platform aims to provide a more immersive learning experience by seamlessly integrating theoretical knowledge with practical applications. The virtual classroom introduces foundational concepts through engaging animated content, followed by interactive simulations. In these simulations, students actively manipulate variables such as air temperature, humidity, and air velocity, enabling them to directly observe the impact of these factors on thermal comfort. This approach not only reinforces theoretical knowledge but also enhances practical skills through simulation-based activities where students apply what they have learned to real-world scenarios. An experimental study involving 66 students was conducted to measure the effectiveness of this educational approach. A pre-test and post-test, each consisting of 6 questions, were administered to assess the students' initial understanding and subsequent knowledge acquisition after using the virtual classroom. The results showed a significant improvement, with a 25% average increase in post-test scores, indicating enhanced understanding and application skills. Additionally, student feedback collected through a survey expressed high satisfaction with the virtual classroom, highlighting its value as an engaging and effective educational tool. Overall, the study confirms that the virtual classroom significantly improves learning outcomes and student engagement in building service engineering education.

Keywords: Engineering Education, Virtual Reality (VR) Technology, Virtual Classroom, Education Experiment

Introduction

In recent years, the advent of Virtual Reality (VR) technology has revolutionized numerous fields, with education being one of the most significantly impacted areas. VR's ability to simulate complex environments and immersive scenarios offers a novel approach to learning and teaching, particularly in technical and scientific disciplines. This research focuses on the application of VR in the field of building service engineering, specifically to enhance understanding of Fanger's thermal comfort model -- a fundamental concept that defines the criteria for maintaining optimal human comfort in built environments.

The increasing reliance on digital technologies in educational settings presents a unique opportunity to leverage VR not only to improve the comprehension of theoretical models but also to facilitate a hands-on approach to learning that traditional methodologies often lack. This study aims to systematically evaluate the effectiveness of a VR platform tailored for education in building service engineering, assessing its impact on learners' knowledge, engagement, and emotional responses.

By investigating these areas, the research will address critical gaps in the literature concerning the effectiveness of VR in enhancing technical education, particularly how it affects different learner demographics such as engineering and non-engineering students. The study's outcomes are expected to contribute valuable insights into the pedagogical potentials and limitations of VR technologies, offering guidance for future implementations in similar technical fields. Through this exploration, the research will help delineate the role of VR in modern education, potentially setting a benchmark for its application in technically oriented academic curricula.

Literature Review

The experiential learning model, as outlined by Kolb in 1984 (Morris, 2020), emphasizes that learners gain practical experience through active participation, which enhances their comprehension of abstract concepts (Morris, 2020). Following these experiences, reflective observation allows learners to further deepen their understanding. A pivotal factor in experiential learning is the creation of a conducive learning environment, which supports learners in actively constructing knowledge and meaning (Jiang et al., 2022; He & Wu, 2006; Hou & Wu, 2020). In such an environment, learners engage with their surroundings, enhancing perception and comprehension. This engagement triggers various cognitive activities including memory retention and imagination, crucial for the acquisition and development of knowledge. An attractive and stimulating learning environment can naturally motivate learners by triggering curiosity and interest, prompting them to actively explore and engage with educational content. In these environments, learners acquire not just knowledge, but also practical skills and attitudes through a combination of hands-on practice and thoughtful reflection.

By the early 2000s, virtual environments began to gain prominence in education, recognized for their potential to significantly enhance learning (Chang et al., 2023). The utility of virtual environments extends beyond their ability to replicate reality; they can also create tailored virtual scenarios that align with specific learning objectives (Meyrowitz, 2002; Chang & Hwang, 2021). The effectiveness of scenario-based teaching does not depend on whether it occurs in a physical "real scenario" or a digital "virtual scenario." Rather, it is determined by the nature and quality of interactions between teachers and students, and the extent of these interactions (Jiang et al., 2022). Effective facilitation of teacher-student engagement in "virtual scenarios" can yield educational outcomes that are on par with those achieved in real-world settings. Ultimately, it is the pedagogical approach and the level of interaction that determine the effectiveness of scenario-based teaching, regardless of the scenario's physical or virtual nature.

A Virtual Classroom Concept for Teaching Indoor Thermal Comfort

Indoor thermal comfort education aims to enhance understanding of the factors affecting occupants' satisfaction with their indoor environment, including ventilation, temperature, and humidity. The subjective nature of comfort and the complexity of these factors make standardization challenging. Virtual Reality (VR) offers an innovative way to merge theoretical principles with practical applications, particularly in fields like building service engineering. This research introduces students to a VR platform featuring a multi-interactive interface, which facilitates learning through hands-on interaction with Fanger's Predicted Mean Vote (PMV) model. This model, essential for assessing indoor thermal comfort, calculates comfort levels based on variables such as air temperature, humidity, and clothing insulation, and is represented on a scale from -3 (cold) to +3 (warm). Educating students on this model can be challenging due to its complex calculations and the dynamic real-world conditions it attempts to represent. To overcome these educational hurdles, the use of practical exercises, simulations, and case studies within the VR environment is recommended to enhance comprehension and application of the model in real-world scenarios.

Research Gaps

Despite the growing integration of Virtual Reality (VR) technologies in educational settings, there remains a significant gap in empirical evidence regarding the specific impacts of VR platforms on learning outcomes in technical disciplines. Previous studies have extensively explored VR's role in general education and training scenarios, but fewer have addressed its application in technical fields like building service engineering, where the integration of theoretical knowledge and practical application is essential. Moreover, while there is some understanding of how VR can enhance learning experiences through immersion and interactivity, less is known about the effects of VR on learners' understanding of complex theoretical models such as Fanger's thermal comfort model. This model, critical in building service engineering, involves intricate concepts that may benefit substantially from the immersive learning environments provided by VR. However, the effectiveness of such platforms in truly enhancing comprehension of these concepts has not been adequately quantified.

Additionally, the impact of VR on different demographic groups, particularly the distinction between engineering and non-engineering students, has not been thoroughly investigated. Understanding how students from various academic backgrounds perceive and benefit from VR could provide insights into the adaptability and inclusivity of VR technologies in diverse educational contexts. Finally, while some research has considered the cognitive and educational benefits of VR, there is a scarcity of studies examining the emotional or affective outcomes associated with VR learning environments. Investigating how these platforms influence learners' mood states is crucial, as emotional engagement is known to enhance retention and deepen learning experiences. Addressing these gaps can provide a more comprehensive understanding of VR's potential as a transformative educational tool, particularly in fields that require a strong linkage between theoretical knowledge and practical application.

Research Questions

The primary objectives of this research are to evaluate the effectiveness of the VR platform in enhancing learners' understanding of Fanger's thermal comfort model, assess learners' overall experiences with the platform, including content quality, sensational experience, integrative experience, engagement and personalisation, and investigate learners' mood states after using the VR platform for educational purposes. By quantifying knowledge gains, exploring user experience, and analyzing emotional impacts, this study aims to provide a comprehensive understanding of the potential of VR as a transformative educational tool in technical fields like building service engineering, where integration of theoretical and practical learning is crucial.

RQ1: How do students perceived the experience of using the VR learning platform?

RQ2: What is the impact of the VR learning platform in enhancing students' knowledge related to Fanger's model?

RQ3: How does students' academic background (engineering vs. non-engineering students) influence the effectiveness of VR platforms in enhancing learning outcomes and perception of virtual environments?

Methodology

Development of the VR Platform

The development framework for the VR platform, as illustrated in Figure 1, is methodically divided into two principal sections: development inputs and user interface components. The development phase is intricately focused on the integration of specialized subject knowledge, specifically Fanger's thermal comfort model, which serves as the educational foundation for the VR content. This integration is coupled with logical interaction mechanisms that are essential for crafting a VR experience that not only mimics real-world scenarios but also engages users deeply. During this phase, sophisticated virtual rendering techniques are employed to construct a visually immersive environment, while advanced algorithms are developed to automate processes and enhance the interactions within the platform. These algorithms are tailored to adjust dynamically to user inputs, providing a responsive and adaptive learning environment that maintains functional viability.

On the user interface front, the platform is engineered to ensure an intuitive and seamless interaction for users. This part of the framework emphasizes creating a fluid user interface that can adapt effectively across different devices and platforms, ensuring a consistent user experience whether accessed via a desktop, tablet, or VR headset. The interface includes user-friendly controls and design elements that not only reflect real-world interactions but also simplify complex concepts, making them easier to grasp. Interactive elements such as draggable components, clickable areas, and immersive animated tutorials are integrated to facilitate active learning and engagement. These interactive components are designed to provide hands-on experience and real-time feedback, crucial for educational effectiveness. The synergistic operation of these components ensures that the VR platform is not just technologically sophisticated but also highly accessible, making it a powerful tool in educational settings where understanding complex models like Fanger's thermal comfort theory is essential.

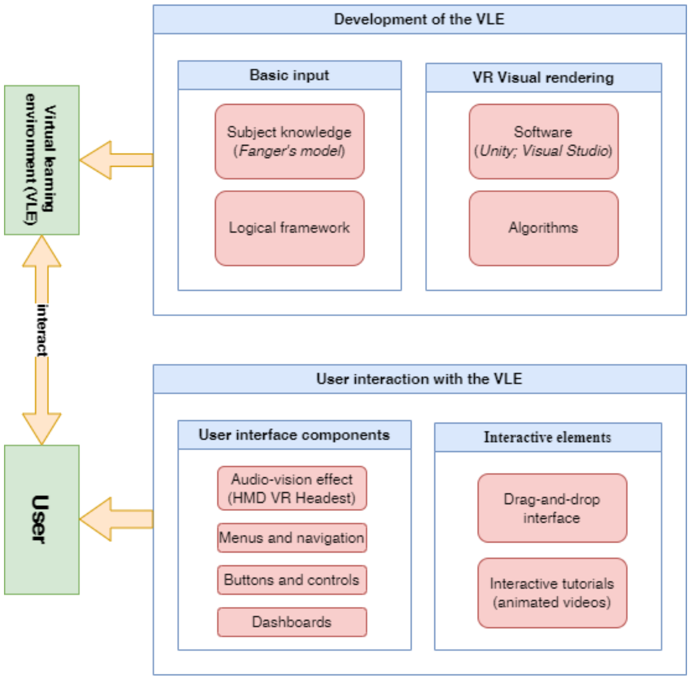

Figure 1: Development Framework of the VR Platform

In this project, the development of a VR platform using OCULUS RIFT and the Unity3D game engine has enabled the creation of a highly immersive educational platform, modelled on an actual university classroom in Hong Kong. This virtual classroom, complete with essential furnishings such as a blackboard and workstations, introduces students to the main contents of the platform (Figure 2a) and the Fanger's thermal comfort model through animated videos (Figure 2b). This video serves as the cornerstone of the learning experience, explaining the educational functions of the environment and guiding students in using the virtual space effectively. The classroom can toggle between "winter" and "summer" modes, reflecting changes in "clothing insulation" - a key variable in Fanger's thermal comfort model (Figure 2c). This feature allows students to understand how different environmental conditions affect thermal comfort, with specific clothing insulation values integrated into the virtual interactions to enhance the educational depth of the experience.

a. Video introduction of the VR platform

b. Introduction of the fundamental theory of the Fanger's thermal comfort model

c. Interactive control and feedback mechanism on mathematic calculation

Figure 2: Three Layers of Interactive Mechanism in the VR Platform

Experiment Design and Implementation.

Based on the research objectives, the methodology is designed on a comparison conducted 1) between students' knowledge level of indoor thermal comfort (Fanger's model) before and after using the VR platform, and 2) between the engineering and non-engineering students who participated regarding their learning performance in an experiment of using the VR platform. Also, participants' experience and perception of using the VR platform, as well as their mood state after the learning activity were assessed through questionnaire survey.

Specifically, a total number of 66 undergraduate students, consisting 32 students majoring in building service engineering and 34 from other academic disciplines, from a university of Hong Kong were recruited to participate in the experiment. The experiment mainly includes three stages: pre-learning activities, learning using the VR platform, and post-learning activities. As the VR platform can only be used by single user, each participant experienced the learning activity on an individual basis. In the pre-learning phase, each student was required to complete a 6-question pre-test, in which he/she also indicated his/her gender and their academic major. After the pre-test, each student was guided to use the VR platform with the help of a research assistant (Figure 3). The learning activity last between 15-20 minutes. In the last stage, participants were required to complete a post-test, which is composed with 6 different questions with the difficulty level escalated above the pre-test. In addition, a survey was delivered to the participants to assess their evaluation of the VR platform and mood states.

a. Experiment supported by an assistant　b. Experiment participant A　c. Experiment participant B

Figure 3: Experiment Participants Using the VR Platform

Table 1: Profile of the Participants

Item	Sub-group	Number
Gender	Female	45
	Male	19
	Prefer not to say	2
Age	16-20	17
	20-25	33
	26-30	10
Academic background	Building service engineering student	32
	Non-engineering students	34

A number of 10 questions were designed to assess quality of the VR platform from three perspectives: content quality, sensational experience, integrative experience, engagement, and personalisation. Table 2 illustrates the 10 evaluation attributes of the VR platform, including adaptability, quality of visual images, multi-model presentation, visual experience, aural experience, user experience, control mechanism, immersion and presence, engagement, and personalisation.

Table 2: Instruments for Evaluating Students' Perception of the VR Platform

Content quality	
Adaptability	The VR learning system is designed to be flexible, accommodating different ways students prefer to learn and study.
Quality of visual images	The VR learning system presents information, like graphs, 3D models, and colors, in a way that makes it easy for students to grasp the concepts.
Multi-model presentation	The VR system uses engaging visuals, sounds, and interactive features to create a rich learning experience that helps you understand and remember information better.
Sensational experience	
Visual experience	The graphics, animations, and visuals in the VR learning system are clear and well-made, making your learning experience enjoyable and effective.
Aural experience	The sound and audio effects in the VR system are high-quality, enhancing your learning with clear and immersive audio.
Interactive experience	
User interface	The VR learning system's menus, buttons, and controls are designed to be user-friendly, making it simple for you to find what you need and interact with the content effortlessly.
Control mechanism	The tools you use to interact with the VR system, like hand controllers or voice commands, work smoothly and precisely, making you feel in charge as you move objects and explore the virtual space.
Immersion and presence	The VR system makes you feel like you're really inside the virtual world, with objects and settings that behave like they would in real life and respond to your actions in a believable way.
Engagement	
Engagement	The VR learning system is packed with fun activities like simulations, group work, and virtual experiments that invite you to take part and learn by doing, making the learning process interactive and engaging
Personalisation	
Personalisation	You can tailor the VR experience to your liking, choosing between text or video explanations to fit your learning style. You have the freedom to tweak settings and controls to match your personal preferences and make the system work just right for you.

Results

Rating of the User Experience Aspects

The evaluation of the VR platform across ten different attributes provides a comprehensive view of its effectiveness from multiple perspectives. Figures 4 illustrates participant feedback on various aspects of the VR system. The ratings generally suggest a favorable user experience across most aspects, except for the "aural experience", which is significantly lower than the other metrics. This implies that while the visual and interactive components are well-received, the audio aspect of the experience may need improvement.

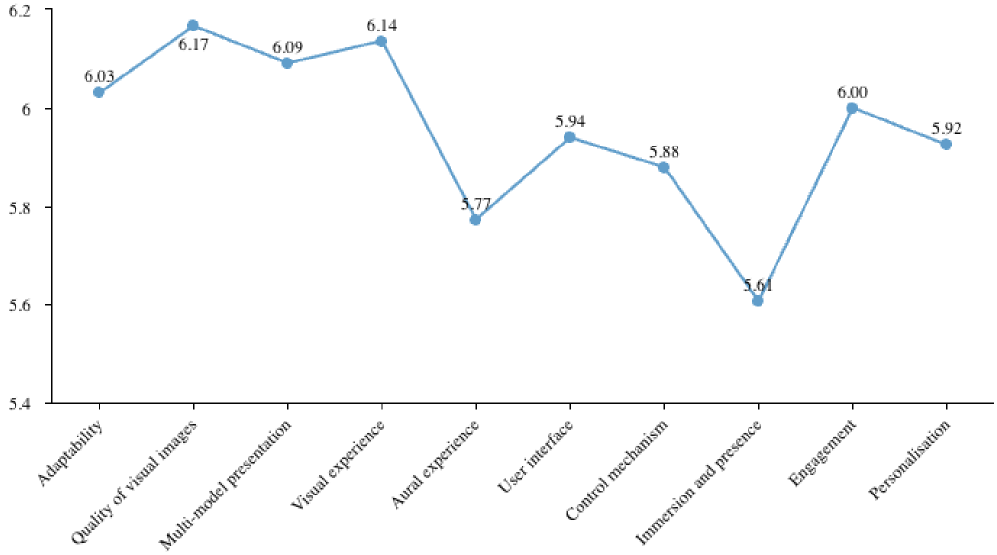

Figure 4: Mean Values of Each User Experience Aspect

Evaluation of the Effectiveness of the VR Platform in Increasing Learners' Knowledge.

Table 3: t-Test for the Pre-Test and Post-Test

Item	Sample size	Mean	S.D.	M.D.	t	p
Pre-test	66	2.68	1.14	-0.42	-2.697	0.009**
Post-test	66	3.11	0.96			

*p<0.05, **p<0.01

Table 3 presents the results of a paired t-test comparing pre-test and post-test scores for a sample of 66 participants. The mean score increased from 2.68 in the pre-test to 3.11 in the post-test, indicating an improvement. The standard deviation decreased from 1.14 in the pre-test to 0.96 in the post-test, suggesting less variability in scores at the post-test stage. The mean difference (M.D.) between the pre-test and post-test scores is -0.42, reflecting this improvement. The t-value for this test is -2.697, which is statistically significant with a p-value of 0.009, indicating that the difference in means is highly significant ($p < 0.01$). This suggests that the changes observed from pre-test to post-test are not likely due to chance, and there is a statistically significant improvement in the scores after the intervention or event being tested.

Table 4: Spearman Correlation Between Changes in Integrated Mood States, Gap Scores, and Quality of the VR Platform

		Gap score (Post-Pre)	Perceived quality of the VR platform
Integrated mood states	**Correlation coefficient**	0.104	0.296*
	p	0.405	0.016
	Sample size	66	66

*p<0.05, **p<0.01

Using correlation analysis to study the relationship between perception of quality and mood states, the Spearman correlation coefficient is used to represent the strength of the relationship. The analysis reveals that the correlation coefficient between Perception and mood state is 0.296, and it is significant at the 0.05 level, indicating a significant positive correlation between perception of quality of the VR platform and integrated mood states.

Table 5: Comparative Analysis of Pre-test, Post-test, and Quality of the VR Platform Between Control and Experimental Groups Using t-Tests

	Item	Sample size	Mean	S.D.	M.D.	CI (95%)	t	df	p
Pre-test	Control group	32	3.00	1.19	0.62	0.074 ~ 1.61	2.271	64.000	0.027*
	Experimental group	34	2.38	1.02					
	Total	66	2.68	1.14					
Post-test	Control group	32	3.19	1.06	0.16	-3.318 ~ 0.634	0.664	64.000	0.509
	Experimental group	34	3.03	0.87					
	Total	66	3.11	0.96					
Quality of the VR platform	Control group	32	5.94	0.87	-0.03	-0.433 ~ 0.367	-0.165	64.000	0.869
	Experimental group	34	5.97	0.76					
	Total	66	5.95	0.81					
Integrate mood state	Control group	32	2.04	1.87	-0.47	-1.227 ~ 0.282	-1.259	47.790	0.214
	Experimental group	34	2.52	1.04					
	Total	66	2.29	1.51					

*p<0.05, **p<0.01; Control group: Building service engineering student; Experimental group: Non-engineering students

Table 5 provides a detailed statistical analysis of the differences between control and experimental groups regarding their responses to pre-test, post-test, and assessments of VR platform quality. The control group, consisting of building service engineering students, initially scored higher on the pre-test with a mean of 3.00 compared to the experimental group of non-engineering students, who scored a mean of 2.38. This difference was statistically significant with a p-value of 0.027, indicating that the engineering students began with a higher baseline in terms of the tested variables. The standard deviations suggest variability within each group, with the control group displaying slightly more variance.

In the post-test scores, both groups showed improvements, with the control group reaching a mean score of 3.19 and the experimental group scoring 3.03, both having tighter standard deviations than in the pre-test. However, the minor mean difference in the post-test scores was not statistically significant (p = 0.509), suggesting that while both groups improved, the degree of improvement was not markedly different between them. Regarding the quality of the VR platform, both groups rated it similarly high with means of 5.94 and 5.97 respectively, and no significant difference in their perceptions (p = 0.869). The mood states also showed changes, but the mean difference was not significant enough to suggest a strong divergence in mood responses between the groups post-intervention, as indicated by the p-value of 0.214. This analysis helps in understanding how different student groups perceive and are affected by VR technology, underlining the uniformity in quality perception despite varying academic backgrounds.

Discussion

Students' Perceptions of the VR Learning Platform

Based on the analysis of user experience aspects (Figure 4) and the ratings given for the quality of the VR platform (Table 5), students generally perceived the VR learning platform positively. Most aspects, such as adaptability, quality of visual images, and multi-modal presentation, received high ratings, suggesting that the platform was effective in delivering a visually and interactively engaging experience. However, the aural experience was rated significantly lower, indicating a potential area for improvement. Despite this, the overall favorable ratings suggest that students found the platform to be a valuable tool for learning, highlighting its potential to enhance educational experiences through immersive technologies.

Impact of the VR platform on Knowledge Enhancement

The results from Table 3, which presents a paired t-test between pre-test and post-test scores, show a statistically significant increase in knowledge after using the VR platform. The mean score improved from 2.68 to 3.11, and the decrease in standard deviation from 1.14 to 0.96 suggests that students' responses became more consistent after using the VR platform. This improvement is statistically significant ($p = 0.009$), indicating that the VR platform effectively enhanced students' understanding of Fanger's model. This result supports the potential of VR as an effective educational tool, particularly in complex subjects where visual and interactive learning can enhance comprehension.

Influence of Academic Background on VR Learning Effectiveness

Table 5 provides insights into how different academic backgrounds affect students' learning outcomes and perceptions when using the VR platform. Initially, engineering students (control group) scored higher on the pre-test compared to non-engineering students (experimental group), suggesting a possible advantage in baseline knowledge relevant to the VR content. However, both groups showed similar improvements and perceptions of the VR platform's quality in the post-test, with no significant differences in their overall ratings. This suggests that the VR platform is equally effective across different academic backgrounds in enhancing learning outcomes and providing a high-quality user experience. The similar perceptions also imply that the VR platform successfully bridges the gap between different academic disciplines, providing a universally engaging and beneficial educational experience.

Conclusion

The investigation into the use of a VR learning platform across different student demographics has yielded insightful results. The VR platform was found to be well-received among students, as evidenced by their positive perceptions especially in terms of adaptability and visual quality. This suggests that immersive technologies like VR can significantly enhance the educational experience by making learning more engaging and interactive. Furthermore, the data demonstrates a clear benefit of the VR platform in improving students' understanding of complex theoretical concepts, specifically Fanger's model. The significant increase in post-test scores confirms that VR can be a powerful tool in educational settings, facilitating a deeper understanding of intricate material.

Additionally, the analysis regarding the influence of students' academic backgrounds -- engineering versus non-engineering -- indicates that the VR platform is versatile and effective across different disciplines. Both groups showed marked improvements in learning outcomes without significant differences in their perception of the platform's quality. This universality underscores the potential of VR as a transformative educational tool that can cater to diverse educational needs and backgrounds, thus democratizing access to high-quality educational technology. Overall, these findings advocate for the broader adoption of VR technologies in educational contexts to enhance learning outcomes and student engagement across various academic fields.

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Contact email: cynthia.hou@polyu.edu.hk