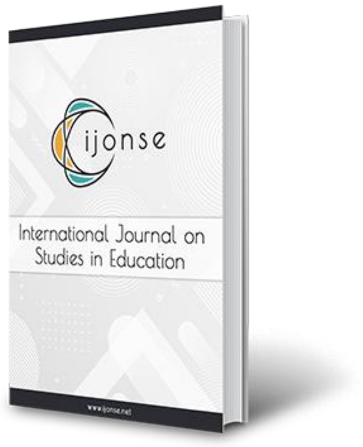

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Abdulrazak Yahya Saleh
Universiti Malaysia Sarawak (UNIMAS), Malaysia

Winchell Alexis Chong Yeng Yong
Universiti Malaysia Sarawak (UNIMAS), Malaysia

Mohd Kamal Othman
Universiti Malaysia Sarawak (UNIMAS), Malaysia

Mohamad Hardyman Barawi
Universiti Malaysia Sarawak (UNIMAS), Malaysia

Shaziti Aman
Universiti Malaysia Sarawak (UNIMAS), Malaysia

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Enhancing Student Engagement in Online Learning through a Peer-to-Peer Virtual Reality Application

Abdulrazak Yahya Saleh, Winchell Alexis Chong Yeng Yong, Mohd Kamal Othman, Mohamad Hardyman Barawi, Shaziti Aman

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Abstract

This study addresses the challenges of reduced student engagement in online learning, exacerbated by the COVID-19 pandemic. It explores the potential of a peer-to-peer learning application using virtual reality (VR) components to enhance student engagement in a Python programming course. The application was developed and tested with university students, focusing on usability, social presence, and learning performance. Usability testing revealed positive perceptions of the virtual classroom's realism, with a mean score of 36.47 out of 45 for realism. Participants also positively viewed the possibility to act and examine the virtual environment. There were concerns about the interface quality, with a mean score of 9.13 out of 15. Self-evaluation of performance was high, with a mean score of 10.33 out of 15. Sound quality was generally perceived positively, with a mean score of 16.07 out of 20. Learning performance showed significant improvement in both traditional (pre-test mean = 8.53, post-test mean = 12.07) and proposed VR learning groups (pre-test mean = 10.03, post-test mean = 15.50). The proposed VR learning method demonstrated a greater increase in knowledge (mean improvement = 5.47) compared to the traditional method (mean improvement = 3.53). Results indicated significant knowledge improvement and positive user feedback, suggesting that VR-based peer-to-peer learning can be a promising approach to improve student engagement in online settings.

Introduction

The COVID-19 pandemic precipitated a rapid and widespread shift to online learning across global institutions, compelling a heavy reliance on digital tools for synchronous classes (Olweny et al., 2023; Schweighart et al., 2024). Video conferencing tools became predominant in facilitating synchronous online learning. However, this transition presented numerous challenges for both students and educators (Belt & Lowenthal, 2023; Pal, 2025). Chung et al. (2020) and Shahzad et al. (2020) highlight the significant and far-reaching impacts of the pandemic on higher education. These challenges included difficulties in gauging student understanding, the loss of informal interactions, and reduced effectiveness in student participation and communication compared to traditional classrooms. Online learning, implemented for daily lessons and academic assessments, contributed to increased stress among students (Irawan et al., 2020). The lockdown period also led to anxiety due to social isolation and the shift to virtual platforms. Nasir (2020), Alexiou & Michalapoulou (2022), and Al Rawashdeh et al. (2021) emphasize the negative impact of lost in-person interaction on students' mental and emotional well-being, with reduced student engagement triggering feelings of isolation and a lack of social presence. Dickinson et al. (2022) found that 63% of participants experienced reduced engagement in virtual lessons due to the lack of visual cues. Al Rawashdeh et al. (2021) further indicated that the absence of face-to-face interaction led to social isolation in 73% of their participants. Hisham et al. (2021) also reported that participants moderately agreed with feelings of isolation (M=3.66) and demotivation (M=3.63) due to the lack of engagement.

Despite these challenges, students still express a preference for online learning when it includes effective feedback from educators (Kang & Park, 2022; Razami & Ibrahim, 2021). As shown in Figure 1, there is a high preference for blended (40.9%) and fully online (4.7%) learning methods. This suggests that digital tools in online courses remain valuable due to their flexibility, even though students may have reservations about online courses. However, synchronous online lessons using video conferencing tools like Webex can be disrupted by delays in chat windows or responses, affecting both students and educators (Park & Sohn, 2023). The constant use of video conferencing has also led to "Zoom fatigue" (Massner, 2021), characterized by exhaustion from online classes and meetings. There is a need for effective solutions to address these negative feelings towards online learning. Current mobile learning platforms like Moodle often lack interactivity, which diminishes student engagement (Salhab & Daher, 2023). While these platforms facilitate information exchange, the absence of face-to-face interaction can lead to social isolation, with 73% of participants in Al Rawashdeh et al. (2021) reporting this issue. The reliance on screens exacerbates this disconnection and hinders collaboration, especially for social learners (Al Rawashdeh et al, 2021). Educators' insufficient proficiency in using advanced digital tools further impedes the implementation of interactive learning methods.

Existing suggestions, such as incorporating avatars or holographic technology, lack empirical support and infrastructure for integration into e-learning environments (Cesari et al, 2021). The interconnectedness of social involvement and presence in digital classrooms necessitates a comprehensive approach to bridge the gap between technological advancements and pedagogical needs, highlighting the need for interactive applications to enhance student engagement through peer-to-peer learning. The limited evidence and exploration of Virtual Environment (VE) efficacy in educational settings further restricts the development of engaging e-learning environments.

Therefore, this study will evaluate the effectiveness of a newly developed application, utilizing a virtual environment to enhance student engagement through peer-to-peer learning. This research aims to develop an online peer-to-peer learning application as an alternative to traditional online learning tools. The specific objectives are: to design an interactive peer-to-peer online learning mobile app for Python programming skills for university students using Virtual Reality components ,to develop a fully functional interactive peer-to-peer online learning mobile app for Python programming skills for university students using Virtual Reality, and to analyze the effectiveness of the learning mobile app in enhancing students' engagement.

This research seeks to answer the following questions:

- What are the usability test results for the newly developed application?

- How effective is the application in establishing social presence and enhancing student engagement?
- What is the difference in students' learning performance between traditional and proposed learning groups?

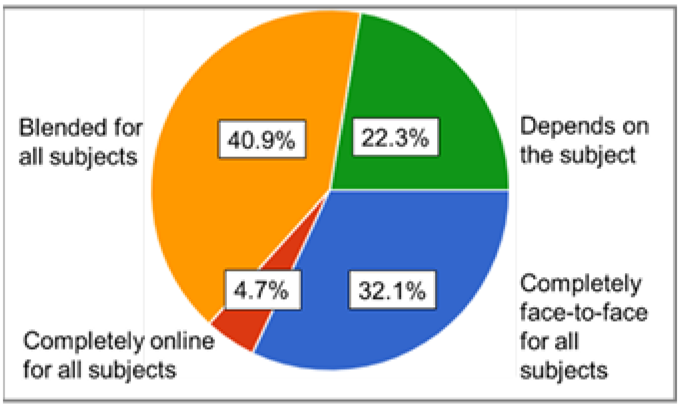


Figure 1. Percentages for Students' Preferred Future Learning Methods (N=408) (Razami & Ibrahim, 2021)

The findings of this study, with its promise to foster student engagement and improve academic outcomes in online settings, have the potential to enhance online education and instructional technology. By introducing a peer-to-peer learning application, the study addresses reduced student engagement, a critical challenge in online learning. Beyond its practical applications in future online courses, this research also explores factors affecting student engagement, contributing valuable insights to the development of effective e-learning environments and providing further evidence for peer-to-peer learning as a valuable online education strategy.

Method

Research Design

As shown in Figure 2, the research design for this study involves a systematic approach to identify and address the causes of decreased student engagement in online learning environments. This study follows the steps of Mobile Application Development Lifecycle (MADLC). This lifecycle comprises of seven stages, namely identification, design, development, prototyping, testing, deployment, and maintenance.

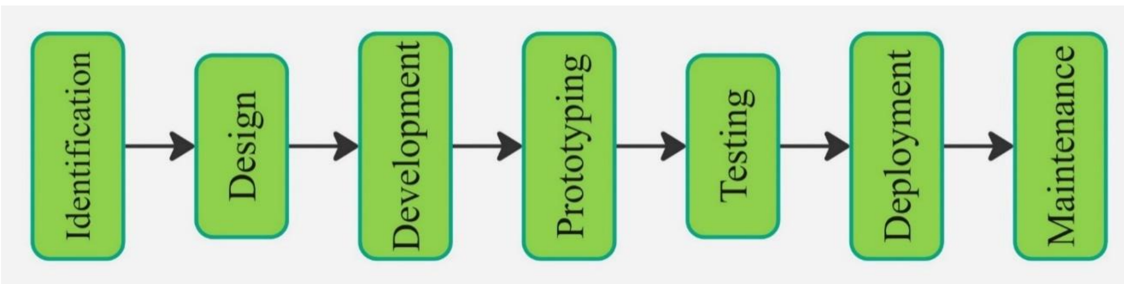


Figure 2. Mobile Application Development Lifecycle (MADLC)

Initially, the focus is on identifying specific problems related to student engagement and interactivity. This involves gathering insights from students who have prior experience with online learning, particularly those familiar with programming courses. The goal is to understand their perceptions, feelings, levels of engagement, and openness to new approaches. Based on these insights, the research proposes developing a mobile application that incorporates peer-to-peer learning as a central feature, leveraging multiplayer gaming concepts to enhance engagement.

Following the identification phase, the design phase involves creating the first draft of the application and conducting a heuristic evaluation to ensure usability and effectiveness. The design process takes into consideration established engagement factors that emphasize learner-to-instructor, learner-to-content, and learner-to-learner interactions. As displayed in Figure 3, Preliminary sketches and scenarios are developed to visualize the key features of the application, ensuring that it aligns with the principles of active and authentic learning. This phase is crucial for brainstorming and refining solutions, ultimately selecting the most promising ideas to enhance student interaction and participation. Additionally, strategies to enhance student engagement in an online setting were carefully considered to optimize the application's effectiveness for subsequent testing. The goal was to maximize student interaction and participation, ensuring that the final design would facilitate meaningful and productive learning experiences.

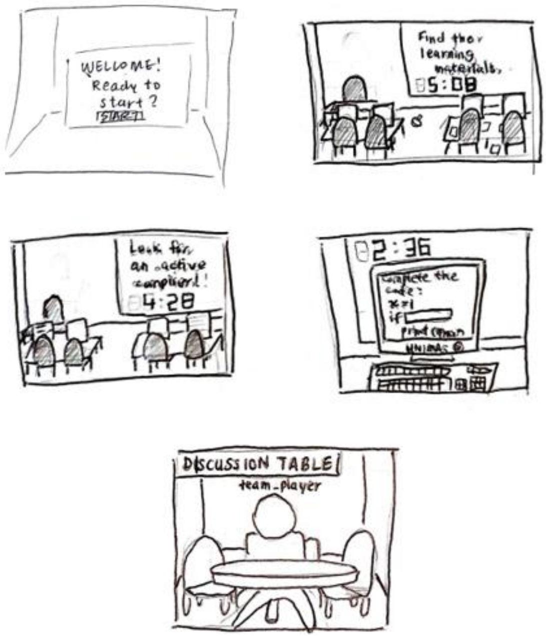


Figure 3. Initial Sketches

In the development phase, the application is constructed using various software packages and developmental kits. Unity 3D, the Android Software Development Kit (SDK), the Native Development Kit (NDK), and Microsoft Visual Studio Code are employed to create a collaborative 3D classroom model accessible to Android users. The application allows users to explore virtual surroundings, interact with learning materials, and participate in discussions within a specified timeframe. The development process emphasizes creating an engaging and interactive learning environment that mimics the dynamics of a multiplayer game, fostering collaboration and engagement among students.

The final stages of the research design involve conducting evaluation techniques to test the low-fidelity prototype, followed by usability testing using the Presence Questionnaire (PQ) and System Usability Scale (SUS). These evaluations assess the application's effectiveness in providing a realistic and user-friendly experience. Once testing is complete, the application is made available for installation on users' mobile devices. The maintenance phase involves ongoing updates and improvements based on user feedback and performance data, ensuring that the application remains effective and relevant in promoting student engagement over time. This comprehensive approach ensures a thorough evaluation and continuous enhancement of the mobile application to meet the needs of students.

Data Collection Procedures

This quasi-experimental study investigates the difference in students' engagement during Python Lab sessions using the mobile application and in traditional classroom settings. The participants of the study consist of 60 Cognitive Science students enrolled in the KMK1143 Foundations of Artificial Intelligence course. As shown in Figure 4, these students are divided into two groups, whereby one group attends the class in a traditional classroom setting while the other group applies the virtual reality (VR) application during the class. The learning materials and duration of the session for both groups remain the same. Since peer-to-peer learning is the main approach, both traditional and VE learning groups will adapt to a peer learning environment whereby students are paired up. Prior to conducting the lessons, each participant is required to fill in a digital consent form using Google Form, requesting for their consents and informing their rights as voluntary participants. The consent form contains information on the study's purposes, its data usage and security as well as warnings of any side effects.

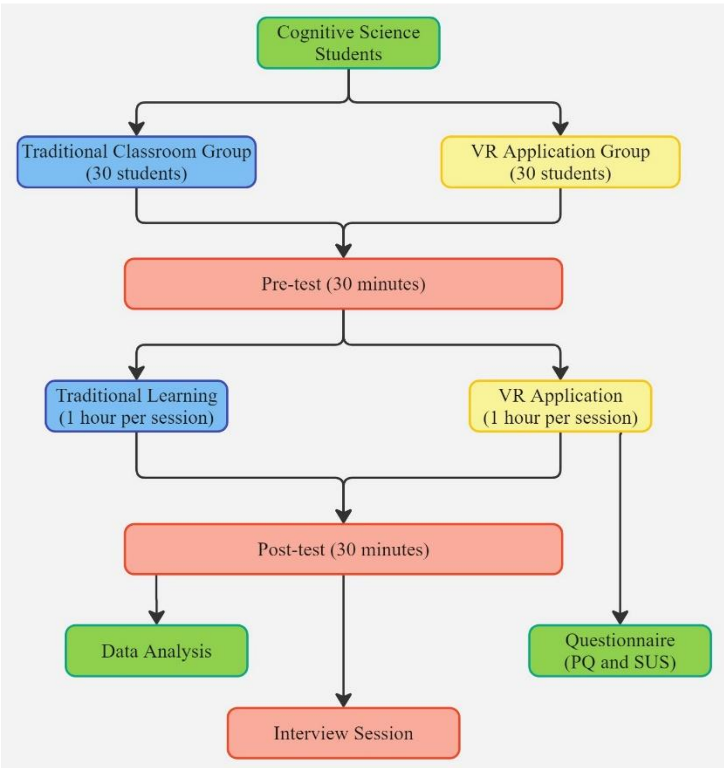


Figure 4. Data Collection Procedures

Student engagement is directly observed through their active participation throughout the lesson and further discovered through interviews post-sessions. Thus, the participants will be given a pre-test prior to the commencement of the session to investigate their existing knowledge of Python programming. They will be reassessed at the end of the session to test for any improvements in knowledge acquisition after the hour of peer learning session. As for the user and usability testing for the VR application, the Presence Questionnaire (PQ), a modification of Witmer & Singer (1998) by Witmer et al. (2005) and System Usability Scale (SUS) by Brooke (2013) will be adopted and distributed after user testing to evaluate the degree of Presence perceived by the user and usability respectively. Additionally, an interview session with the users will be conducted to receive feedback and in-depth insights.

Data Analysis

The study utilizes quantitative and qualitative data to evaluate students' engagement. The results obtained from pre-tests and post-tests are examined to check for knowledge improvement in students' engagement through traditional and proposed learning groups using Statistical Package for Social Science (SPSS). The qualitative data from interview sessions and observations will be used to support quantitative data findings.

Results

This section presents the findings of the study, including the results from the user survey, the pre-and post-tests for both learning groups, the system usability scale (SUS) questionnaire, and the Presence Questionnaire (PQ).

User Survey Results

The survey was swiftly administered during a physical session with the constant group using an interactive presentation tool with real-time feedback, Mentimeter. Each question was opened for discussion, allowing unlimited responses from all survey participants. After removing noise (e.g. irrelevant answers or emoticons), majority of responses indicated that students find online classes to be challenging and often negative. This feedback suggests that students not only struggle with the difficulty of the material in an online setting but also experience a range of negative emotions and perceptions. These responses highlight issues such as lack of engagement ("boring"), anxiety and pressure ("stress", "scary").

Figure 5 depicted self-reported feedback on their perceptions towards online classes in general. When asked, "What do you think of online lessons?", participants provided a variety of responses that highlight their opinions and assessments of the online learning experience. Some found online lessons to be "interesting," "interactive," and "useful," appreciating the flexibility and accessibility they offer. Others described them as "hard," "complicated," "hard to follow," and "confusing, a little bit difficult," indicating challenges in understanding and keeping up with the material. Several respondents mentioned that online lessons were "hard but fun" and "enjoyable but hard," reflecting a mixed experience of difficulty and enjoyment. Some participants found online lessons "stressful" and "boring," while others labelled them as "joyful," "nice," and "fun." Terms like "challenging," "advance," and "scary" also appeared, showcasing a broad spectrum of opinions on the effectiveness and engagement of online lessons.

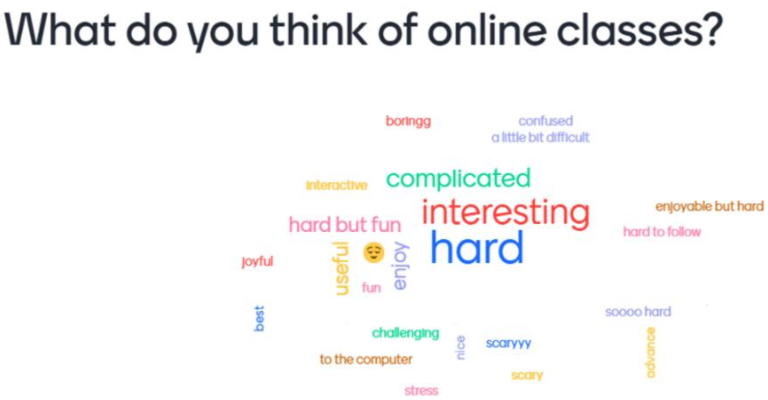


Figure 5. Mentimeter Presentation Responses on "What do you think of online classes?"

In response to the question, "How do you feel about online lessons?", which seeks to understand the emotional reactions of participants, a wide range of feelings were expressed as shown in Figure 6. Some participants found online lessons to be "fun and exciting" and "discoverable," enjoying the new way of learning despite its challenges. However, many reported negative emotions such as feeling "sleepy," "exhausted," "stressed," and "drained," highlighting the toll that continuous online engagement can take. Others felt "nervous," "boring," and "hard to catch up," suggesting difficulties in maintaining focus and understanding the material. Responses like "fifty-fifty," "average," and "mix feelings" indicated ambivalence, reflecting both positive and negative aspects of their experiences. Some students felt "forgetful," "cannot understand," and "blur," pointing to issues with retention and clarity, while others expressed feelings of "complicated so far," "hard but enjoyed," and "struggle," showing resilience and a willingness to adapt despite the difficulties.

Figure 6. Mentimeter Presentation Responses on "How do you feel during online classes?"

When asked, "How concentrated, involved, and engaged do you get during online classes?", the responses varied significantly among participants. Only one participant (0-24%) reported minimal engagement, while a notable number, 18 participants (25-49%), indicated a moderate level of involvement as presented in Figure 7. The largest cohort, comprising 34 participants (50-74%), reported a fairly high level of engagement during online classes. However, only 4 participants (75-100%) indicated a high degree of concentration and involvement in their online learning sessions. These findings suggest that while a subset of students can maintain moderate to high levels of engagement, a considerable portion experiences lower levels of concentration and involvement in online classes.

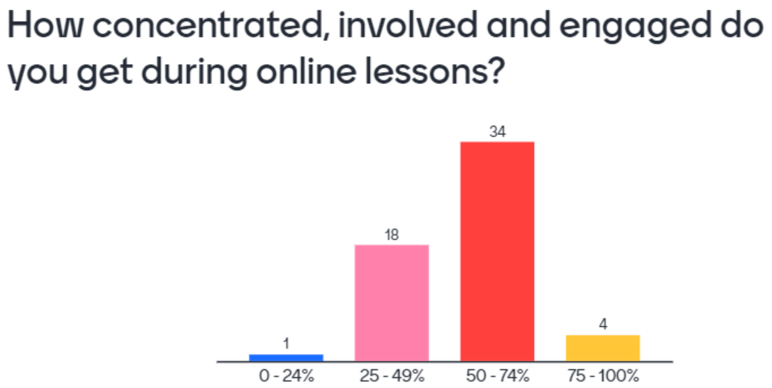


Figure 7. Mentimeter Presentation Responses on "How concentrated, involved and engaged do you get during online classes?"

When asked, "Are you willing to try new approaches (e.g., Games, VR environments, etc.)?", the responses were predominantly positive. A substantial majority, 53 participants, responded with "Yes, of course," indicating a willingness to explore innovative methods in their learning. Conversely, 10 participants expressed a preference for traditional methods, stating "Normal is okay." These results shown in Figure 8 suggest a general openness among the majority of students to incorporate new and interactive approaches in their education.

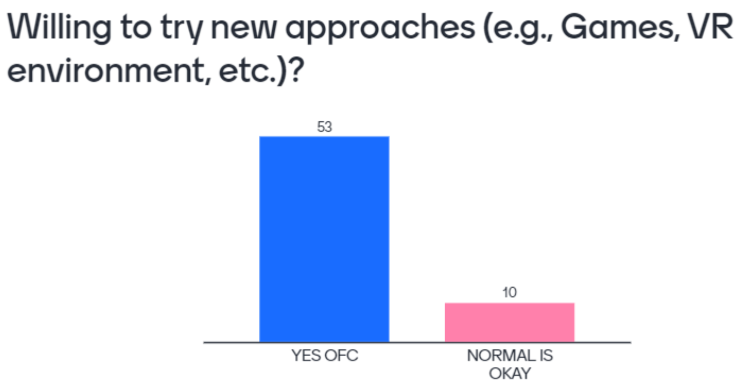


Figure 8. Mentimeter Presentation Responses on "Willing to try new approaches (e.g.: Games, VR environment, etc.)?"

Mobile Application Development

Design Phases

The design phase consists of the flow and outlook of the application as shown in Figure 9. The outlook of the application started off with designing a virtual environment, mimicking that of a computer lab room. Virtual objects relating to physical objects in the real world such as chairs, computers and desks were added to complete the imitation. The interactions with the system and virtual objects were only added after the floor plan was completed. The final outlook of the application includes four desks with a computer and four chairs on each. The instructor's computer table is placed at the front of the virtual classroom along with a projector mirroring the instructor's computer screen.

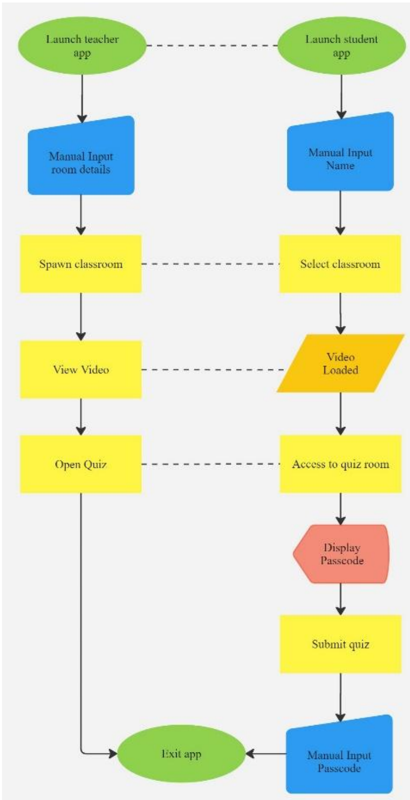


Figure 9. System Flowchart of Application

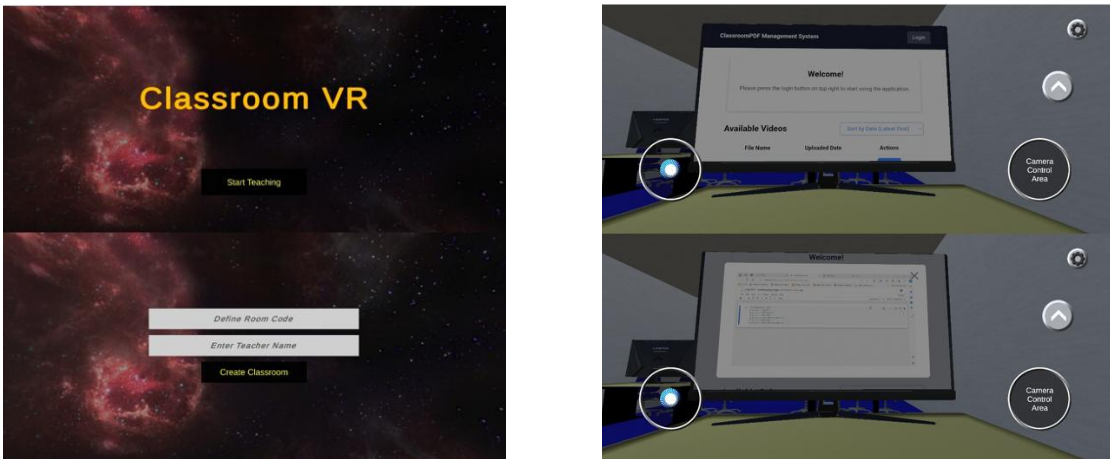
The interactions of the virtual objects in the virtual environment differs between the instructor and student. There is a total of two scenes on the application. The first scene encompasses the computer lab room, and the second scene incorporates a Quiz Room. In the computer lab room, the instructor's computer can be controlled by scrolling up and down and clicking on buttons while the students' computers can only click on play buttons. However, outside of the application, the instructor can access a webpage and is required to register as a teacher to upload videos and set up quizzes by submitting a Google Form (Quiz) link which will be immediately reloaded in the application. The second scene can only be viewed on the student's application where they would be alone to complete the task of the day.

In the second scene, the quiz room is set up to mimic a simple escape room with the exit programmed to be accessible only after completion of task. The quiz room is designed to contain two computer screens and an interactive projector on the side of one of the four walls with no doors.

The virtual objects and their interactions can be summarized with the system flowchart of the Mobile Application Development Lifecycle (MADLC) below. It outlines the sequential steps and interactions within the teacher and student applications. Firstly, the teacher launches the teacher app and spawns a virtual classroom, setting up the environment for student engagement. Concurrently, students launch their respective apps and select the classroom to join after a quick input for their names. The teacher then loads the video content, which students can view at their own pace. For assessment purposes, the teacher accesses the quiz room and opens it for students, who subsequently transition to the quiz room, complete the quiz, and submit their responses. Both the teacher and students have the permission to exit the app after the quiz submission, ensuring a structured and comprehensive flow of activities within the virtual classroom environment.

Development and Prototyping Phase

The initial idea of developing an application was modified due to time constraints. Consequently, instead of a single application accommodating various users with diverse functionalities, the project was divided into two separate applications: one tailored for students and the other for teachers.



(a) (b)

Figure 10. a. Interface and b. Functionalities on Teacher App

On the teacher's interface (see Figure 10.a), the initial screen prompts to "Start Teaching", enabling teachers to create a classroom. The instructor or teacher is required to input a room code and their names which will be reflected on the student's app. After inputting proper room codes and names, the instructor can click on the "Create Classroom" button directly beneath the input boxes. A 3D virtual classroom mimicking of a real-life computer lab room is spawned immediately, and the initial setup is as shown in the figures below. The initial setup includes an interactive computer displaying a fully functional webpage (https://classroompdf.web.app/) which is accessible outside the application.

The initial setup also includes a camera control area (see Figure 10.b) where users can move their viewpoints at a 360-degree angle, a joystick to manipulate movement around the virtual environment and a jump button. This setup remains the same for the student's application as well except they are unable to use the joystick in the first scene to keep the class coordinated. The instructor's functionalities in the first scene include viewing the lecture video and opening quiz room for students which can be done using the interactive computer on the instructor's desk.

Throughout the development, several problems arose in conjunction with the initial ideas of the application. The application prompt to tackle the lack of social involvement in existing online meeting platforms thus the microphone feature was indispensable. Initially, the webpage, classroompdf.web.app, provided the function to upload pdfs but due to lower resolutions of the pdfs on the student application, the idea was refined to upload video presentations instead. After refining the resolutions and loading process, the application was able to present videos.

Upon accessing the application, users will view a quick registration feature which will prompt a list of currently available classrooms for users to select from. The application launches the first screen for students to "Start Learning" and prompts students to input their name before joining a classroom. A sample of a room was created to show how the list of available classrooms will appear. An affordance to instruct on how to access to desired classroom is displayed below the room details ("Tap to join this room"). Upon clicking, students are immediately transported to a 3D classroom with a clear indication of the microphone being switched on (see Figure 11). At the early stages during development, other students are firstly designed to be viewed as a cylindrical shaped body. This feature was not enhanced later to create avatars due to insufficient development time.

The student app includes microphone features to support its peer-to-peer learning approach, enabling an open flow of discussion throughout the classroom. This mirrors the conduct of a traditional class where students engage in respectful and focused discussions rather than speaking loudly or to their friends.

Figure 11. Initial View on Student App

For every consecutive user, they are automatically placed at the first table beside their peers. The instructor possesses the capability to stream a video which is later reflected on the interactive computer screen within student app denoted by the appearance of a play button, indicating the video is ready to be played (see Figure 12). Access to the video content is not limited to users seated at the same table; instead, each user has the autonomy to control playback, allowing for individualized learning at their preferred pace. The camera control area enables users to adjust their view, while the movement joystick on the left side operates similarly to those in mobile games.

However, the joystick is only operational within the quiz room.

Figure 12. Play Video on Student App

The instructor has access to an "Open Quiz" button, which transitions all students from the current classroom to a new quiz room (see Figure 13). This room features two interactive computer screens: one displaying classroompdf.web.app for quiz access and another hosting a Jupyter Notebook for practicing Python coding. Students access the quiz by scrolling to the bottom of the webpage and selecting "Attempt Quiz." Upon initiating the quiz, the passcode required to exit the room is revealed, ensuring students are informed. The passcode can be set up along with the quiz link by the instructor using the webpage as shown in Figure 14. The passcode becomes functional only after students have submitted their quiz responses via a Google Form, thereby enforcing quiz completion before exiting.

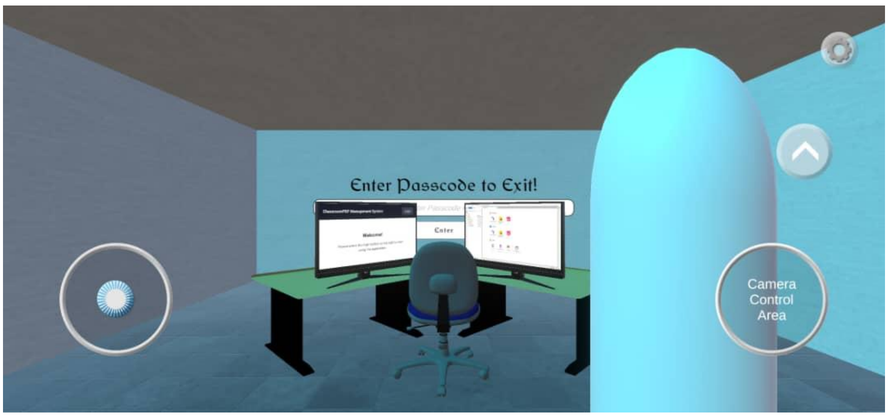


Figure 13. Initial View of Quiz Room on Student App

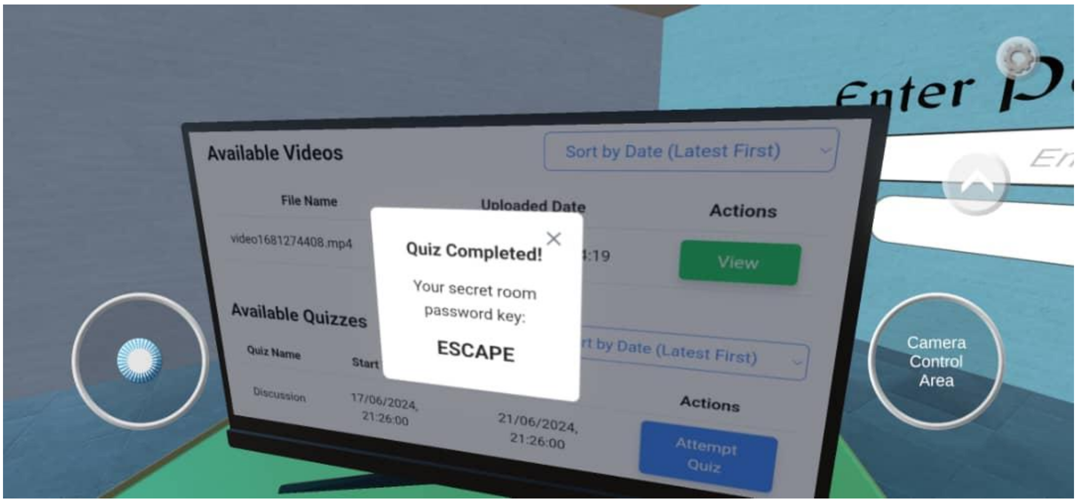


Figure 14. Password Key Information

After the quiz submission, (see Figure 15), the password is once again displayed at the end of the Google Form. This is to ensure that users have continuous access to critical information necessary for subsequent tasks or access, reducing the likelihood of forgetting or misplacing the information. Students can move closer to the screen projection by using their joysticks on the left and type in the password. Upon keying in, the screen displays one of two things: "ERROR" if keyed in password is incorrect or "CORRECT PASSWORD" if the password is correct. In the first context, the screen will go back to displaying "Enter Password" where as in the second context, the screen will display "You may now leave…" indicating a clear pass on exiting the application by closing the application window in the mobile phone's application history tab.

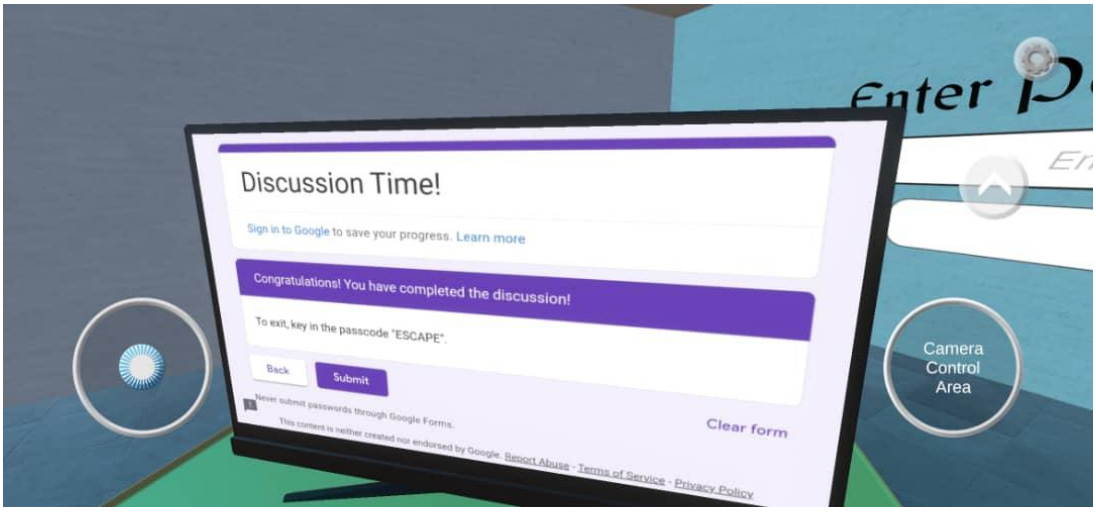


Figure15. Quiz Completion on Quiz Room

The settings page (see Figure 16) is accessible by clicking on the universal settings icon at the top right of the screen. For the VR+DPad input method, the application provides a 360-degree view of the classroom with just moving the phone around unlike the Mobile method where users can move their view using the camera control area on the right. To adjust the sensitivity of the camera tilt, there is a slider feature that allows students to customize the sensitivity based on their preferences.

Figure 17 illustrates the main dashboard of the webpage classroompdf.web.app, which is displayed on both the instructor's computer and the student's application in the quiz room. This main dashboard is accessible without requiring a sign-in as either an instructor or a student. It provides a comprehensive overview of available videos and quizzes, including specific details such as the upload dates of the videos and the start and end dates of the quizzes. This interface allows users to view videos and attempt quizzes at the click of respective buttons "View" and "Attempt Quiz".

Figure16.VR+DPad Setting

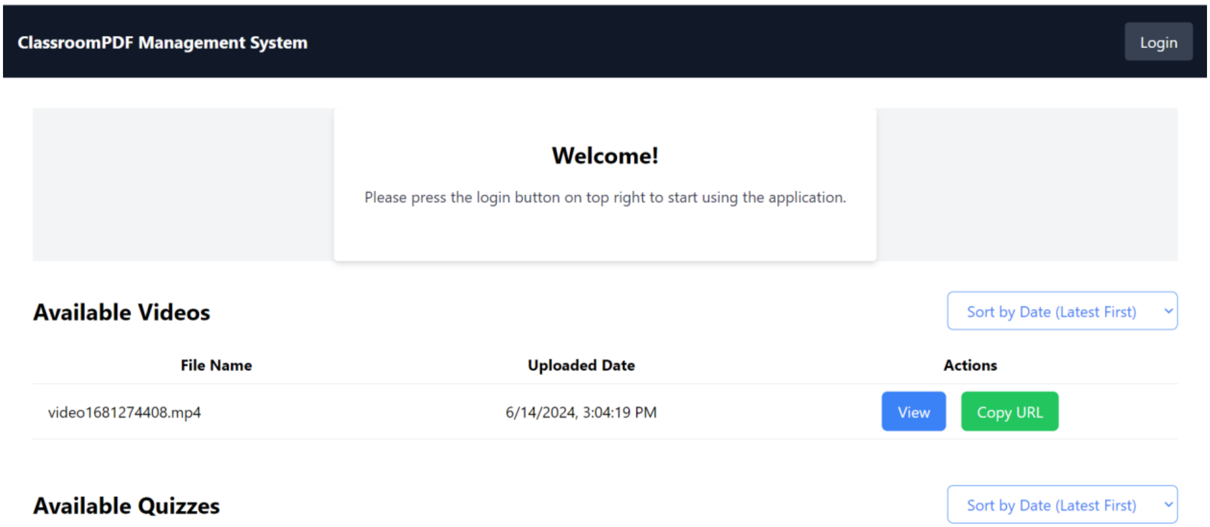


Figure17. Main Dashboard on Webpage (classroompdf.web.app)

The "Login" button, located at the top right corner of the screen, directs users to the Sign In page where both students and instructors can authenticate using their email address and password. This page includes an option to save credentials under the "Remember Me" checkbox. For failure management, users can click on "Forgot Password?" in the event of an error during the sign-in process. The Sign Up page is accessible via the "Create New Account" link, allowing users to register with their email and password, specifying their role as either a student or teacher. Users can return to the Sign In page by clicking on the "Already have an account? Login" text button.

During usability testing, a significant setback was identified on this page. If students inadvertently clicked on “Login” in the application during the second scene in the quiz room, they were unable to return to the main dashboard without registering and signing in as a student, which was not part of the assigned tasks. Consequently, they were compelled to exit the application, rejoin the classroom, and wait for the instructor to reopen the quiz room.

Upon signing in, the primary dashboard presents a comprehensive list of uploaded videos associated with the signed-in instructor. This list includes details such as the File Name, Uploaded Date, and Action. The Action column features several buttons, including “View,” “Copy URL,” and “Delete.” This page is accessible by selecting the “File Listing” tab located on the left side of the webpage.

As previously mentioned, instructors have the capability to upload pre-recorded video presentations in .mp4 format. This functionality reduces the additional workload of uploading content to external streaming sites, such as YouTube, by providing a similar upload process to that found in MS Teams. Instructors can initiate the upload process by clicking the “Add File” button, which allows them to either drag and drop a file directly from their personal computers or laptops or click within the designated empty space to upload from their File Explorer. To return to the primary dashboard without uploading any files, instructors can click the “X” located at the top right corner of the pop-up box.

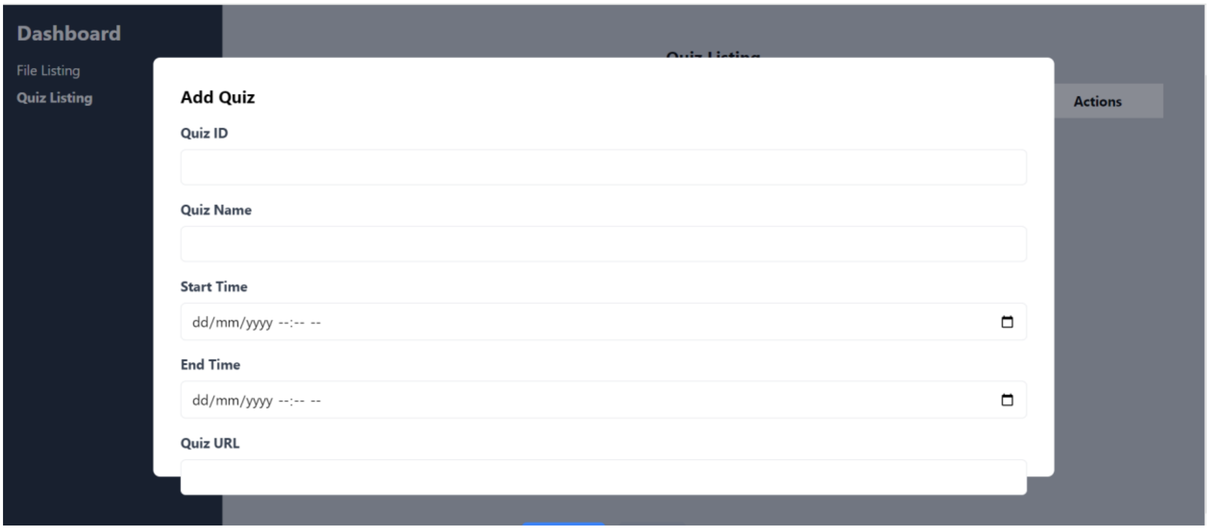


Figure18. Input Details of Quiz on Webpage (classroompdf.web.app)

Instructors can access the "Quiz Listing" tab located on the left side of the webpage to view a comprehensive list of quizzes they have uploaded (see Figure 18). This list includes important details such as the Quiz Name, Quiz ID, Quiz URL, Start and End Time, and Actions. The Actions column contains two buttons: "Edit" and "Delete." To add a new quiz, instructors can click the "Add Quiz" button, which will prompt a text form message box requesting the necessary quiz information. It is important to note that the "Quiz ID" functions as the password students must input to correctly exit the application.

Although students are not required to register in order to access the videos and quizzes, a registration process is available to address any potential access issues through the application. Figure 19 illustrates the primary dashboard that a student encounters upon signing in. This dashboard provides comprehensive information regarding the quizzes available to the student, including the Quiz Name, Start and End Time, and an Action feature which includes an "Attempt Quiz" button. This interface is designed to facilitate straightforward navigation and interaction with the quiz content. Additionally, students have the option to log out after completing their quizzes or daily tasks using the logout feature located at the top right corner of the webpage.

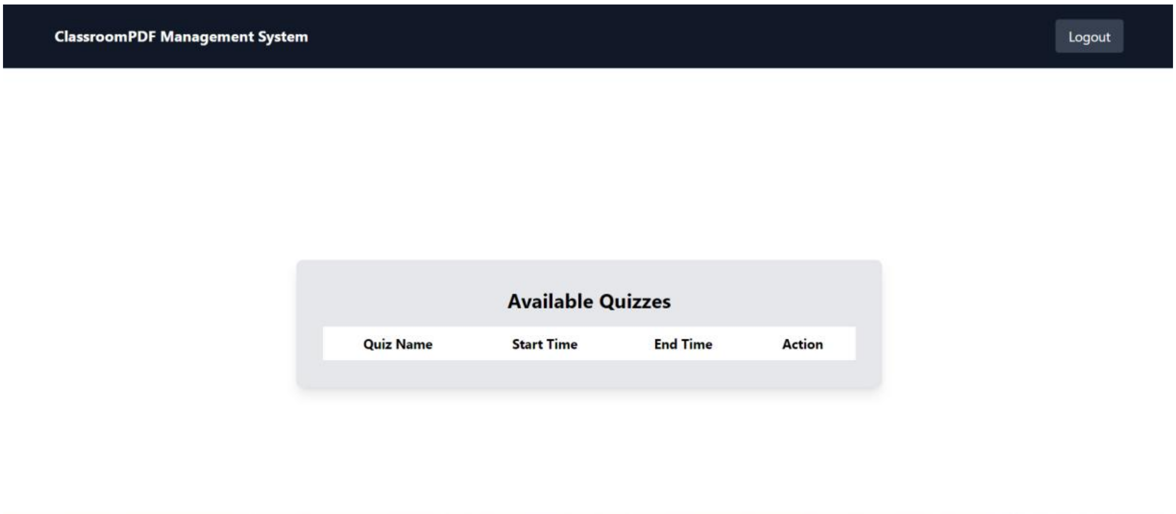


Figure19. List of Available Quizzes upon Student's Login

Testing and Deployment

The testing was completed after refining errors and ensuring a smooth flow of the application. Deployment of the application was conducted in a group of students with instructions given throughout the session from the researcher. First, the traditional learning session is conducted using presentation slides with the researcher assuming the lecturer role (see Figure 20).

Figure 20. Traditional Learning Session

To ensure the learning method to be the sole variable, the learning materials remained the same for both traditional and experimental group with exact contents. Before the learning commenced, pre-test is conducted using a website called Quizizz. To measure any changes or improvements in gaining knowledge, post-test is also conducted using Quizizz after the learning session. Both the pre-test and post-test, 20-items multiple choice questions (MCQ), contain the same contents to maintain a consistent difficulty level to guarantee that students' responses are not influenced by external variables. The comparison of pre-test and post-test scores offers valuable insights on knowledge improvement before and after the learning sessions.

The video presentation utilized in the application was pre-recorded with the same content as the presentation slides used in the traditional learning session. Similarly to the traditional learning group, pre-test and post-test were completed outside of the application before and after commencing the learning session using the application (see Figure 21). The sudden increase in users during the first round of testing caused the application to crash and lag for over a span of 10 minutes. Despite early warnings to limit the number of users, students were curious to try out for themselves. Thus, at the start of the second round of testing, the number of users entering the application was limited to 4 at a time.

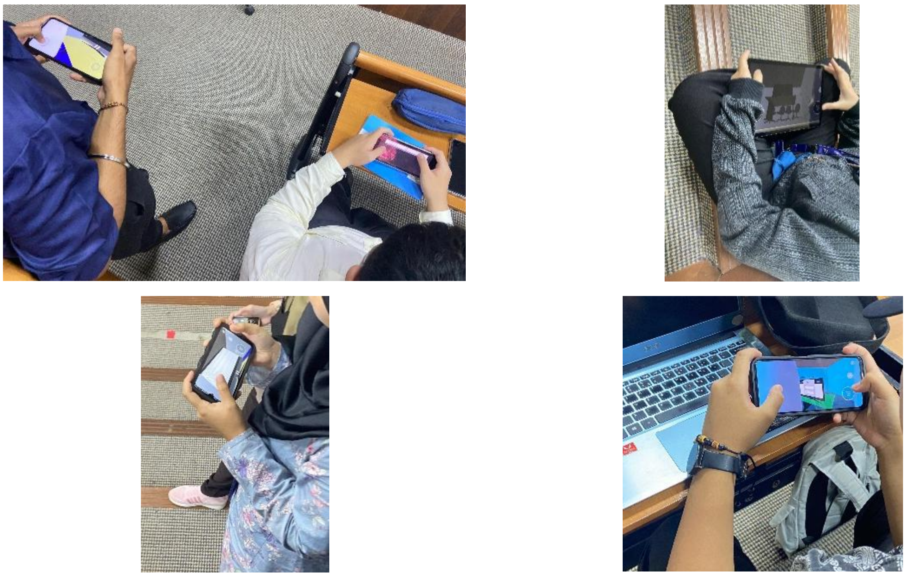


Figure 21. Proposed Learning Session

To maintain a consistent level of difficulty, the pre-test and post-test questions remained identical for both groups. Each question was designed and derived from the learning materials to ensure alignment with the content covered during the respective sessions for both the traditional and proposed learning groups. Since the application is reportedly to teach undergraduates enrolled in the course Foundations of Artificial Intelligence, the topics covered consists of basic Python programming topics such as if-else and loops. The pre-tests and post-tests were administered following the learning sessions using the customizable learning content tool, Quizizz.

Figure 22 illustrates a 20-item quiz designed to be completed at the participants' own pace in Classic Default mode. This mode individual completion ensuring that the questionnaire results are not influenced by any of Quizizz's game elements.

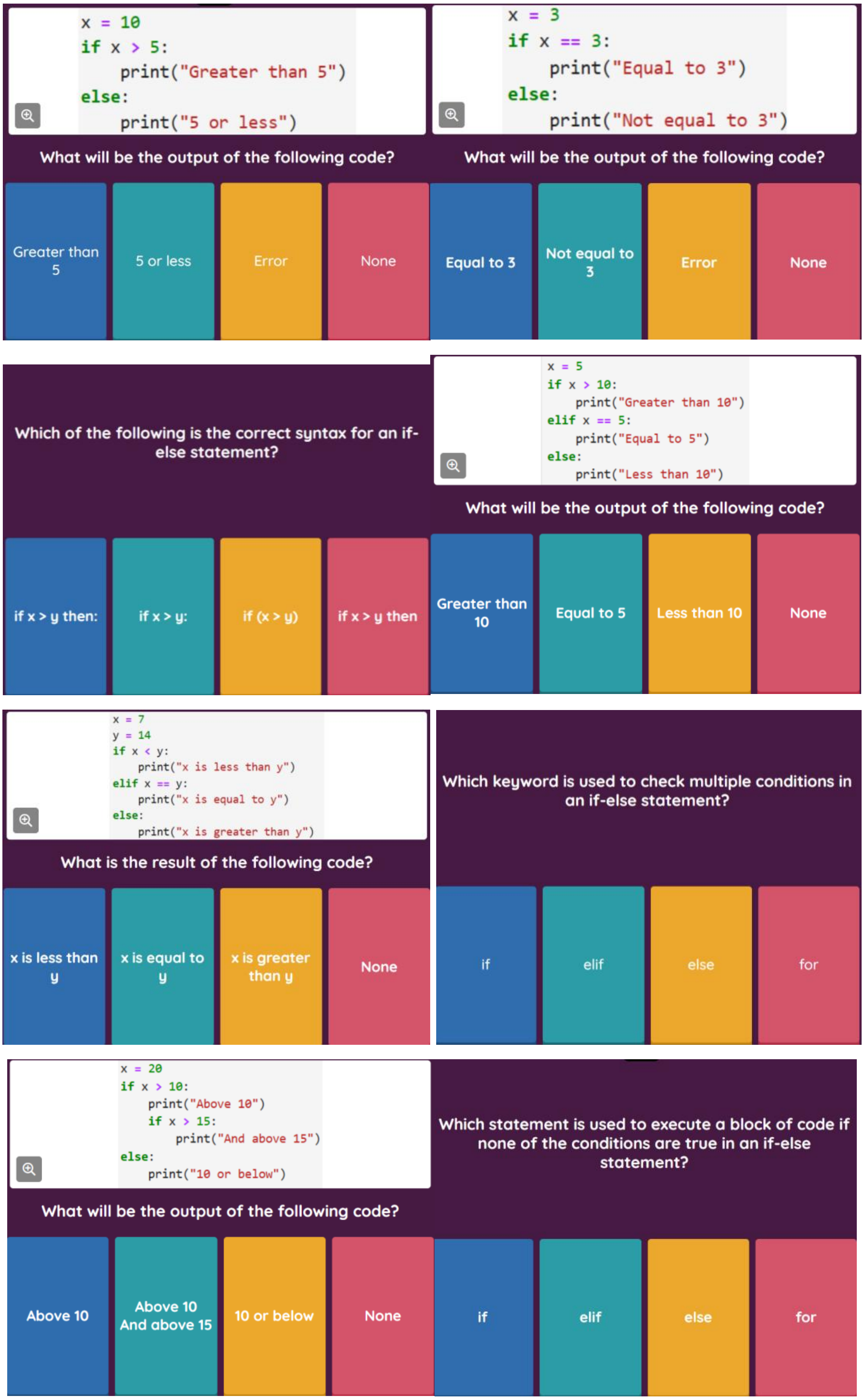


Figure 22. 20-Item Quiz for Pre-test and Post-test

Results of the Proposed Learning Method

Results of Pre-Test and Post-Test via Traditional Method

Table 1 shows the descriptive statistics of the traditional learning group. The data for pre-test includes the total ($n = 30$), mean ($M = 8.53$) and standard deviation ($SD = 2.897$) while the data for post-test includes the total ($n = 30$), mean ($M = 12.07$) and standard deviation ($SD = 2.970$). Table 2 shows the dependent t-test results comparing the pre and post-tests with the computed significance value ($p = 0.00000017239$).

Table 1. Descriptive Statistics of Pre-test and Post-test for Traditional Learning Group

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	post	12.07	30	2.970	.542
	pre	8.53	30	2.897	.529

Based on t-distribution table (see Table 2) with selected significant level of 0.05 and degree of freedom of 29, the critical value of t-distribution, $t_{critical} = 1.699$. By substituting pre-test and post-test scores, the t-score computed, $t_{statistic}$, $t(29) = 6.821$ which falls at the far-right hand side of the t-graph and thus, much greater than the critical value. Since $p < 0.05$ and $t_{statistic} > t_{critical}$, these results provide sufficient evidence to reject the null hypothesis that indicates a knowledge improvement via traditional learning method.

Table 2. Results of Pre-test and Post-test for Traditional Learning Group

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	post - pre	3.533	2.837	.518	2.474	4.593	6.821	29	<.001	<.001

Results of Pre-Test and Post-Test via Proposed Learning Method

Table 3 exhibits the descriptive statistics based on the results of the proposed learning group. The overall results for pre-test and post-test computed the data, $N = 30,\ M = 10.03,\ SD = 3.285$ and $N = 30,\ M = 15.50,\ SD = 2.945$ respectively. Table 4 shows the results of dependent t-test comparing pre-test and post-test of proposed learning group with the computed significance value ($p = 0.0000000049469$).

Table 3. Descriptive Statistics of Pre-test and Post-test for Proposed Learning Group

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	POST	15.50	30	2.945	.538
	PRE	10.03	30	3.285	.600

Based on t-distribution table (see Table 4) with selected significant level of 0.05 and degree of freedom of 29, the critical value of t-distribution, $t_{critical} = 1.699$. By substituting pre-test and post-test scores, the t-score computed, $t_{statistic}$, $t(29) = 8.192$ which falls at the far-right hand side of the t-graph and thus, much greater than the critical value. Since $p < 0.05$ and $t_{statistic} > t_{critical}$, these results provide sufficient evidence to reject the null hypothesis that indicates a knowledge improvement via proposed learning method.

Table 4. Results of Pre-test and Post-test for Proposed Learning Group

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	POST - PRE	5.467	3.655	.667	4.102	6.832	8.192	29	<.001	<.001

Comparison of Improvement Results for Traditional and Proposed Learning Method

Table 5 shows the descriptive statistics on the improvement results of both traditional (Group 1) and experimental groups (Group 2). The overall results for knowledge improvement computed for traditional and experimental groups are $N = 30,\ M = 3.5333,\ SD = 2.83735$and $N = 30,\ M = 5.4667,\ SD = 3.65526$ respectively. Table 6 shows the computed results for independent sample t-test where the significant value computed is, $p = 0.026$.

Table 5. Descriptive Statistics of Improvement Results via Traditional and Proposed Learning Method

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Improvement	1	30	3.5333	2.83735	.51803
	2	30	5.4667	3.65526	.66736

Based on t-distribution table (see Table 6) with selected significant level of 0.05 and degree of freedom of 58, the critical value of t-distribution, $t_{critical} = 1.672$. By substituting pre-test and post-test scores, the t-score computed, $t_{statistic}$, $t(58) = 2.288$ which falls at the right-hand side of the t-graph and thus, greater than the critical value. Since $p < 0.05$ and $t_{statistic} > t_{critical}$, these results provide sufficient evidence to reject the null hypothesis that indicates a more significant improvement in experimental group as compared to traditional group.

Table 6. Independent Sample t-test Results of Improvement Results

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Improvement	Equal variances assumed	3.188	.079	-2.288	58	.013	.026	-1.93333	.84482	-3.62442	-.24225
	Equal variances not assumed			-2.288	54.639	.013	.026	-1.93333	.84482	-3.62664	-.24003

Results of Questionnaires

Simple metrics regarding the application's usability were assessed during user testing, including the time taken, number of errors, and task completion rate. During usability testing, interventions were conducted only when users needed assistance to proceed, ensuring that variables did not influence their feedback on the System Usability Scale (SUS) questionnaire. Direct observation was carried out by closely monitoring participants as they interacted with the application, observing their actions, behaviours, and any difficulties encountered. The average time required to complete each task was calculated and is reported in Table 7.

Table 7. Average Time taken for Completion of Tasks

Task	**Average Time Taken**
Enter the virtual classroom	34 secs
Explore microphone feature with other students	12 secs
Click on play button and start learning	9 mins 38 secs
Complete the quiz	8 mins 46 secs
Enter passcode to exit the app	18 secs
Total	19 mins 28 secs

It is important to note that the time taken for several tasks exhibited outliers, as more than one participant encountered issues with the application's smoothness, which affected the completion of certain tasks. The time recorded for five participants during Task 1, Task 2, and Task 5 ("Enter the virtual classroom," "Explore the microphone feature with other students," and "Enter the passcode to exit the app") did not deviate significantly from the average time calculated, with all five participants completing Task 1 within 19 to 56 seconds, Task 2 within 9 to 15 seconds and Task 5 within 14 to 23 seconds. In contrast, Task 3 and Task 4 showed the most considerable variation in completion times. Task 3 ("Click on play button and start learning") ranged from 48 seconds to 15 minutes, while Task 4 ("Complete the quiz") ranged from 6 minutes 15 seconds to 13 minutes 23 seconds.

As Table 8 presented, five participants were recruited to perform five tasks without a specified duration. Three participants managed to complete the first three tasks with little to no problem in the virtual classroom. However, participant 3 and 4 encountered slight errors in Task 1 in which participant 3's device did not show any classrooms in the list of available classrooms screen whereas participant 4 could not access to the virtual classroom after selecting to enter. The problem seemed to be due to participants' phone models as after restarting the application, both participants managed to locate and enter the virtual classroom successfully. This problem also affected Task 3 which comprised of video loading and playing on the monitors in participants' mobile phones. Participant 3 was reportedly using 2019 Samsung model while participant 4 was using an Honor brand.

The following tasks were completed after participants were transferred to a virtual quiz room. For Tasks 4 and 5, all five participants were able to submit their answers and exit the application. However, participant 3 had a minor problem with typing on the monitor, as her device would not close her keyboard after filling in her answers. Consequently, participant 3 took a longer time than the average time taken for task 4. The total time reported in Table 8 encompasses the entire session for each participant, including the transition between tasks or scenes and intervention periods. Thus, the average time taken for a user to complete a whole session was 21 minutes and 25.4 seconds.

Table 8. Usability Testing Results

Task	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Enter the virtual classroom	0:27, No error, Complete	0:19, No error, Complete	0:40, 1 error (Slow loading of listed classrooms), Complete	0:56, 1 error (Unable to select classroom), Complete	0:28, No error, Complete
Explore microphone feature with other students	0:15, No error, Complete	0:10, No error, Complete	0:13, No error, Complete	0:13, 1 error (No sounds detected), Incomplete	0:09, No error, Complete
Click on play button and start learning	15:00, No error, Complete	15:00, No error, Complete	0:48, 1 error (Unsuccessful loading), Incomplete	2:23, 1 error (Video stopped), Incomplete	15:00, No error, Complete
Complete the quiz	6:15, No error, Complete	7:18, No error, Complete	13:23, 1 error (Unable to minimize keyboard), Complete	8:46, No error, Complete	7:52, No error, Complete
Enter passcode to exit the app	0:16, No error, Complete	0:18, No error, Complete	0.23, No error, Complete	0:14, No error, Complete	0:21, No error, Complete
Total time taken	24:13	25:05	17:27	14:32	25:50

Demographic Information of Participants

Prior to executing learning methods, participants were required to report their learning history and preferences through a Google Form. The study comprised a total of 60 participants, all of whom are enrolled in the course of Foundations of Artificial Intelligence as required for first-year undergraduates in Cognitive Science programme. The traditional and experimental group are pre-assigned based on their selected class time slots (see Figure 23).

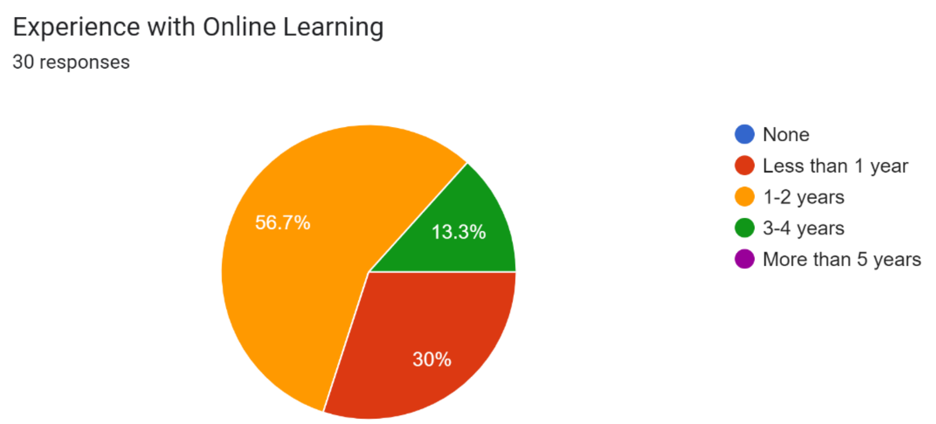


Figure 23. Pie Chart of Participants' Experience in Online Learning (Traditional Group)

As shown in Figure 24, the charts above depicted participants' years of experience in online learning between 0 to more than 5 years. All 60 participants had prior experience in online learning, with majority of them stating 1 to 2 years' experience followed by 21 out of 60 participants having less than a year of experience. Among them, 13.3% of the traditional group participants and 16.7% of the experimental group participants experienced 3 to 4 years. Lastly, 10% of the experimental group participants had more than 5 years for online learning experiences.

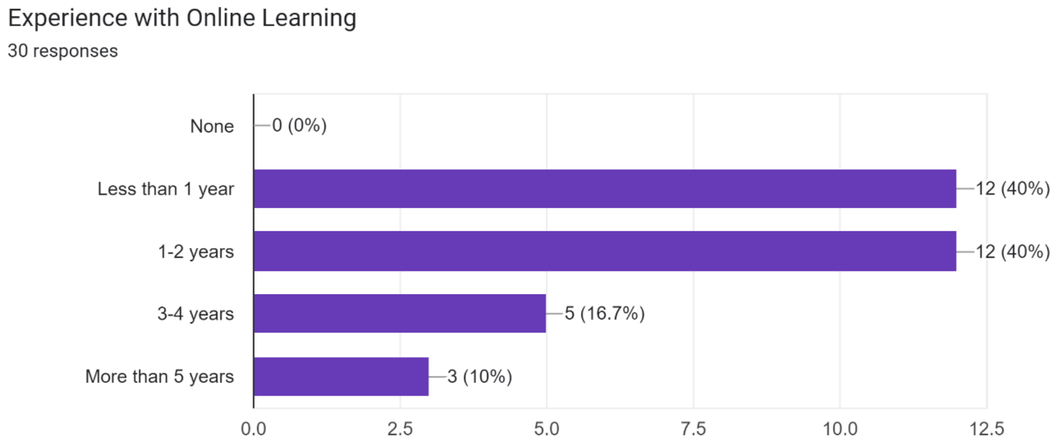


Figure 24. Bar Chart of Participants' Experience in Online Learning (Experimental Group)

Table 9 and Figure 25 illustrated the participants' preferred learning styles of both groups. While each participant in the experimental group had chosen one preferred style, participants in the traditional group selected more than one style, majority of which had selected a combination of visual, auditory and kinesthetics. Meanwhile, 10 participants (33.3%) in the experimental group selected Visual learning style. 10 participants (33.3%) chose Kinesthetics learning style, followed by 6 participants (20%) preferring Reading/Writing. Also, 3 participants (10%) selected Auditory as their preferred learning style while 1 participant (3.3%) chose all the learning styles.

Table 9. Participants' Preferred Learning Styles (Traditional Group)

Preferred Learning Styles	**Count**
1. Visual (e.g., videos, diagrams)	5
2. Reading/Writing (e.g., textbooks, articles)	1
3. Kinesthetics (e.g., hands-on activities, simulations)	1
4. Visual (e.g., videos, diagrams) + Auditory (e.g., lectures, discussions)	3
5. Visual (e.g., videos, diagrams) + Reading/Writing (e.g., textbooks, articles)	1
6. Visual (e.g., videos, diagrams) + Kinesthetics (e.g., hands-on activities, simulations)	5
7. Visual (e.g., videos, diagrams) + Auditory (e.g., lectures, discussions) + Reading/Writing (e.g., textbooks, articles)	4
8. Visual (e.g., videos, diagrams) + Auditory (e.g., lectures, discussions) + Kinesthetics (e.g., hands-on activities, simulations)	6
9. Visual (e.g., videos, diagrams) + Reading/Writing (e.g., textbooks, articles) + Kinesthetics (e.g., hands-on activities, simulations)	1
10. Visual (e.g., videos, diagrams) + Auditory (e.g., lectures, discussions) + Reading/Writing (e.g., textbooks, articles) + Kinesthetics (e.g., hands-on activities, simulations)	3
Total count	30

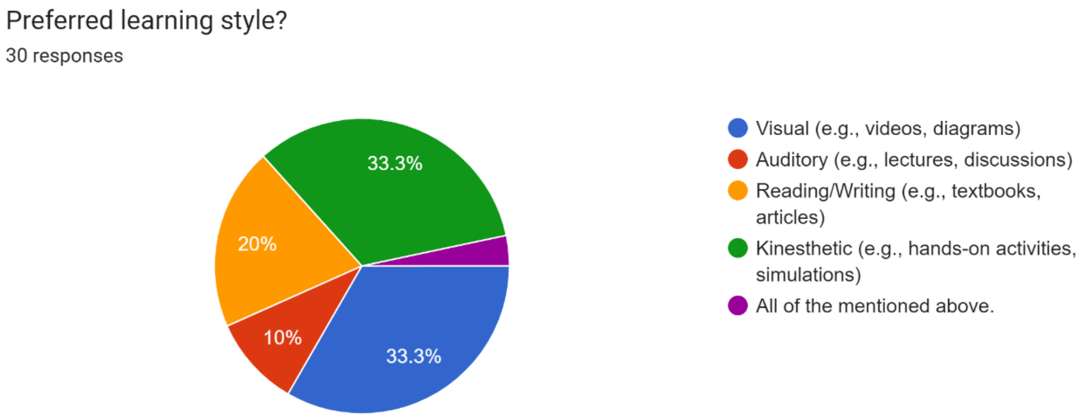


Figure 25. Pie Chart of Participants' Preferred Learning Styles (Experimental Group)

System Usability Scale (SUS) Questionnaire

SUS was utilized to evaluate students' perception towards the usability of the application. The score classification is generalized according to the ranges as presented in Table 10. The results from 30 participants were depicted in the pie chart below (see Figure 26) where majority rated it as awful and poor with 17 and 10 participants representing 57% and 33% respectively. However, results from 1 participant representing for 3% and 2 participants representing 7% rated the usability as excellent and good respectively.

Table 10. General SUS Score Classification

Score	Grade	Adjective Rating
> 80.3	A	Excellent
68 – 80.3	B	Good
68	C	Okay
51 – 68	D	Poor
< 51	F	Awful

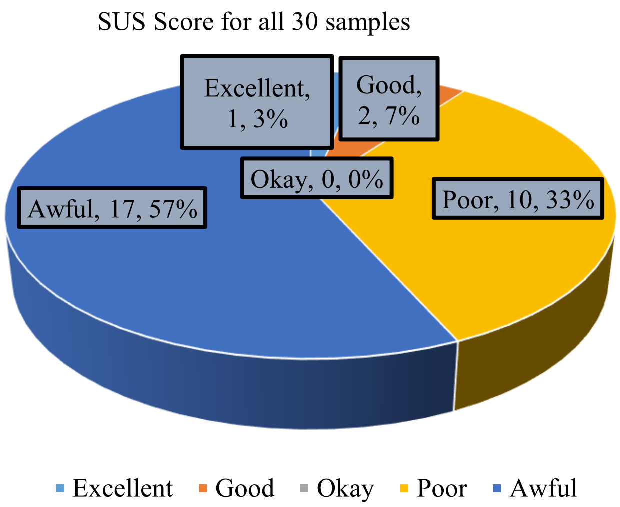


Figure 26. Pie Chart of SUS Score Results

Presence Questionnaire (PQ)

Furthermore, as shown in Table 11, PQ was conducted to assess their sense of presence during usability testing. The realism of the virtual classroom was perceived positively with moderate variability. Participants also viewed the possibility to act and examine within the virtual environment positively. However, there were concerns about the quality of the interface, indicating lower perceived quality. Participants expressed high self-evaluation of their performance in the virtual classroom. Sound quality was generally perceived positively, with some variability in participant responses.

Table 11. Presence Questionnaire (PQ) Score Results

Criterion	Mean	Standard Deviation
Realism	36.4667	4.79032
Possibility to Act	20.1000	3.20936
Quality of Interface	9.1333	2.77592
Possibility to Examine	15.6333	2.14127
Self-evaluation of Performance	10.3333	1.68836
Sounds	16.0667	2.83978

Discussion

Based on the analysis conducted, it concludes the proposed learning method is better than the traditional learning method in improving students' learning performance. During implementation, students appeared intrigued with the virtual application with an enthusiasm to test out the application on their mobiles. They were responsive in completing the tasks to experience the full intentions of the application from beginning to end. Thus, the application in the form of a 3D virtual environment appeal to students as to the usual video conferencing tools such as Webex or Zoom. These findings are consistent with the study by Najjar et al. (2022), which demonstrated that the 2D virtual classroom platform "Gather.Town" contributed to a sense of being in a classroom and provided a tangible representation of a traditional classroom environment.

The open mic concept was to advocate for the peer-to-peer learning. Peer-to-peer learning in a traditional setting allows students to create a social environment conducive for academic and personal improvement. In an online setting, these same students are unable to freely communicate during discussions as frequently used online meeting tools have no way of promoting freedom of speech unless students are prompted by their leader or the meeting coordinator. However, since the application lacks the option to turn off the microphone, one student remarked during the interview on the "need to find a room that is quiet."

In addition to direct observation during deployment, several students were invited for brief interviews to gain a deeper understanding of their experiences with the 3D virtual classroom application. One student reported that the app provided a sense of "being in a classroom but at the same time, we are actually not". This is in line with Chessa et al. (2021) with their students feeling the ability of seeing others in a classroom was helpful to feel the presence. In terms of improving the immersion the virtual environment can bring, the idea of VR glasses was brought up during interviews. While some participants reported it was impossible to attend over an hour of class using VR glasses, it is proved the glasses boost the overall presence one feels (Yoshimura & Borst, 2020). Another student appreciated the "open mic concept," stating that "especially when you are to have a discussion, it is necessary” and that users "can ask questions straight on." A suggestion to enhance engagement was "if you add avatars, they would be able to distinguish" allowing students to "direct speech to which one". However, one student opposed the development of additional online meeting platforms, expressing that they were more "comfortable to talk in person". Additionally, students expressed concerns regarding the open mic concept, made remarks that finding a quiet room might be challenging.

While most participants reported an overall negative perception on the usability of the application, it is evident a certain level of presence is achieved as the overall results reported by PQ are significantly positive. A deeper analysis into the usability questionnaires highlighted a significant consensus on training before utilizing the application regularly, as most participants acknowledged the need for technical aid. Despite initially perceiving the app as unnecessarily complex, participants generally agreed it becomes user-friendly as they are quick to adjust to the virtual environment, feeling confident once they received technical assistance.ence list. Conversely, ensure that every entry in the reference list has a corresponding in-text citation.

Comparison with Previous Studies

Figure 27 shows a virtual reality platform called Mozilla Hubs, closely similar to the developed application with the virtual environment encompassing that of a real classroom and the teaching material is in the form of a video presentation. However, the additional functionalities for students, including that of Microsoft Teams where they can type in a meeting chat and switch on their microphones, are moving around as an avatar and adding virtual objects to the virtual classroom scene.

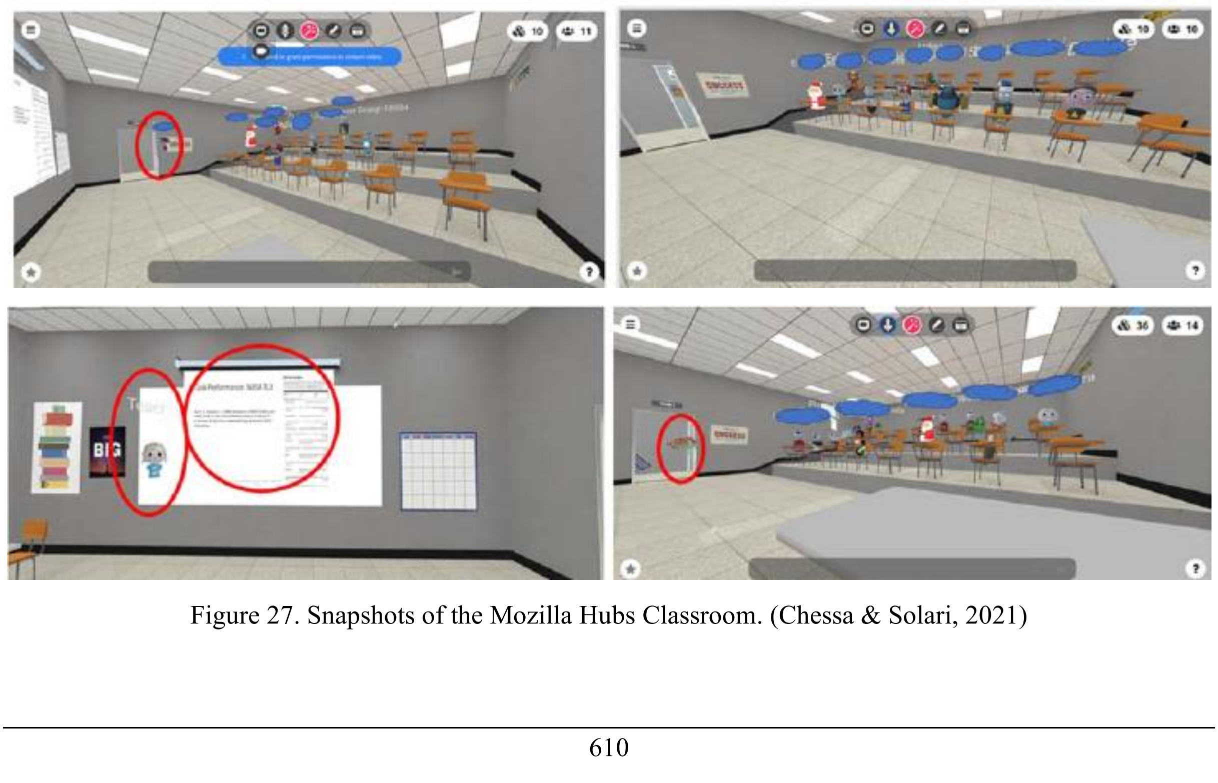


Figure 27. Snapshots of the Mozilla Hubs Classroom. (Chessa & Solari, 2021)

Compared to the developed application, there is no change in scene throughout the class session and no exceptions to switching microphones off. The results for the study are as reported below using Igroup Presence Questionnaire (IPQ), Slatter-Usoh-Steed Presence Questionnaire (SUS Presence), User Experience Questionnaire (UEQ) and System Usability Scale (SUS) instead.

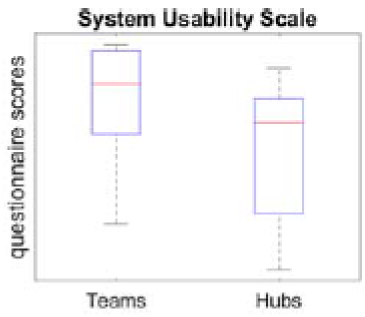


Figure 28. Boxplots Representing the Median Value and the Box of the 25th and 75th Percentiles of the Score for the SUS Questionnaire. (Chessa & Solari, 2021)

Overall, the responses from the participants from the study by Chessa & Solari (2021) are similar to the responses from our study despite the application containing additional functionalities with positive feedback on the virtual environment promoting the sense of 'being in a real classroom'.

Table 12. Averaged Scores of the Questionnaires Divided Concerning the First and the Second Lecture and Overall Results. (Chessa & Solari, 2021)

	Lec. 1 (first)		Lec. 2 (second)		All	
SUS Presence	T	3.3 ± 0.9	H	4.4 ± 0.8	T	2.8 ± 1.2
	H	3.8 ± 1.0	T	2.6 ± 1.3	H	4.2 ± 0.9
IPQ Spatial Presence	T	2.9 ± 1.9	H	3.8 ± 1.6	T	2.8 ± 2.0
	H	3.5 ± 1.8	T	2.7 ± 2.1	H	3.7 ± 1.7
IPQ Involvement	T	2.0 ± 1.9	H	2.7 ± 1.9	T	2.0 ± 1.8
	H	2.8 ± 1.8	T	2.0 ± 1.8	H	2.7 ± 1.8
IPQ Realism	T	2.5 ± 1.8	H	3.8 ± 1.9	T	2.2 ± 1.8
	H	2.2 ± 1.6	T	1.8 ± 1.7	H	2.6 ± 1.8

A comparison between the study by Chessa & Solari (2021) and current study showed findings from questionnaires were also in line with the current study as participants reported a high level of sense of presence. Both usability results also reported a need to learn how to use the application with assistance. In Table 12, participants using Microsoft Teams is denoted as 'H' while participants using Mozilla Hubs is denoted as 'T'. In the current study, participants are divided into traditional learning and VR application learning groups. Specific details can be seen in Figure 28.

As shown in Figure 29, a study by Lee et al. (2022) had similar methodological design which is to assess the effects in self-efficacy using virtual and augmented reality system to teach as compared to a traditional setting. The study also incorporates the idea of collaborative learning with its students divided into groups of five.

However, the study conducted its sessions weekly over a total of five sessions with a decreasing trend in interest from the students over successive sessions. Lee et al. (2022) proposed that higher self-efficacy reports a more active engagement in classes. Thus, findings from the study's (Lee et al., 2022) interview were in line with the current study whereby engaging socially with encouragement from other students enhances their overall learning experience especially with their senses heightened during the use of the VAR system.

Figure 29. Interactive and Immersive Learning of Engineering (Lee et al., 2022)

Conclusion

This study has made several notable contributions to the fields of online education and virtual learning environments. The research effectively demonstrated the potential of 3D virtual classrooms to cultivate immersive and interactive learning experiences. Positive feedback regarding the sense of presence and realism within the application supports its effectiveness in simulating a traditional classroom environment.

Quantitative data from the System Usability Scale (SUS) and the Presence Questionnaire (PQ) further substantiate the application's capacity to create a compelling virtual learning space. The findings indicate that students can engage with learning materials more effectively within the virtual environment, with the open mic feature successfully promoting peer-to-peer discussions akin to those found in traditional classrooms. Furthermore, the study underscores the critical importance of providing robust technical support and comprehensive user training to ensure ease of use and maximize the application's potential within educational settings.

However, the study also encountered several limitations. Initial deployment revealed technical challenges, including application crashes and lag due to high user traffic, necessitating restrictions on concurrent user numbers. Usability testing highlighted device-specific issues, with certain mobile models experiencing difficulties in accessing the virtual classroom and loading videos. The study's reliance on self-reported data obtained through questionnaires introduces the potential for bias, and the limited sample size of 60 participants restricts the generalizability of the findings.

Additional limitations include the restricted ability of users to manipulate 3D virtual objects, which reduced immersion and interaction, and the use of mobile devices instead of VR headsets due to resource constraints. This reliance on mobile devices may have introduced variability in user experience due to differences in device capabilities and performance. The flow of testing sessions, limited to predefined tasks, may not fully capture the dynamics of actual learning sessions, potentially affecting the generalizability of user engagement findings. The study's focus on the application's design, development, and effectiveness in enhancing student engagement did not account for participants' cumulative grade point average (CGPA), preferences, experiences, or proficiency with advanced technology, which may introduce bias..

Recommendations

Based on the findings and limitations of this study, several recommendations can be made for future research and practice. Future studies should prioritize enhancements to the application's technical infrastructure to accommodate higher user capacity and ensure compatibility across a wider range of devices. Replicating this study with larger and more diverse participant pools is essential to further validate the results and improve generalizability. Long-term studies investigating the impact of 3D virtual classrooms on learning outcomes and student engagement should also be considered.

To enhance immersion, interaction, and overall learning experience, future development efforts should focus on incorporating features such as customizable avatars, advanced interaction tools, and the ability for users to manipulate 3D virtual objects within the environment. Researchers should aim to test the application with VR headsets to provide a more comprehensive evaluation of its potential benefits. Additionally, future research should explore flexible system designs that accommodate diverse instructional methods and teaching styles, as well as consider the variability in teaching approaches and their potential impact on student engagement.

To mitigate potential biases, future studies should consider selecting participants with similar levels of experience or academic achievement. Comparative analyses between CGPA and learning gains derived from the application could provide deeper insights into the application's impact on diverse student populations. Comparative studies between different virtual learning platforms could also provide deeper insights into the most effective design elements for online education. Finally, educational institutions should consider integrating advanced virtual learning tools into their curricula, while also addressing technical challenges and ensuring device compatibility for the widespread adoption and success of virtual learning environments.

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Author Information

Abdulrazak Yahya Saleh
https://orcid.org/0000-0003-4485-9901
Universiti Malaysia Sarawak (UNIMAS)
94300 Kota Samarahan Sarawak
Malaysia
Contact e-mail: *ysahabdulrazak@unimas.my*

Winchell Alexis Chong Yeng Yong
https://orcid.org/0009-0005-0492-1231
Universiti Malaysia Sarawak (UNIMAS)
94300 Kota Samarahan Sarawak
Malaysia

Mohd Kamal Othman
https://orcid.org/0000-0001-5401-2515
Universiti Malaysia Sarawak (UNIMAS)
94300 Kota Samarahan Sarawak
Malaysia

Mohamad Hardyman Barawi
https://orcid.org/0000-0003-4014-313X
Universiti Malaysia Sarawak (UNIMAS)
94300 Kota Samarahan Sarawak
Malaysia

Shaziti Aman
https://orcid.org/0000-0001-8785-4022
Universiti Malaysia Sarawak (UNIMAS)
94300 Kota Samarahan Sarawak
Malaysia