Development and Evaluation of Virtual Reality Classrooms Through User-Centered Design During COVID-19

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ABSTRACT
The COVID-19 pandemic has radically changed the way students learn and engage with their peers and instructors. Likewise, instructors had to quickly transform their course materials to suit the online classroom format. Results from a survey of students at an educational institution revealed that perceived levels of learning and collaboration were lessened with the transition to online learning. In this research, we developed a VR classroom through user-centered research and assessed feedback from the students. The goal of the VR classroom was to minimize the pain points of traditional online classrooms as denoted by the survey results while enabling better experiences. Participants rated the VR classroom to be more engaging, fun, immersive, and collaborative than the video conference classroom. Our research indicated VR classrooms improve learning and immersion outcomes and discovered that the greatest detractor from the VR classroom is the inability to take notes, which is an important feature for future research. In this paper, we also report on the future direction of the study focusing on the security component of the VR classrooms.

Author Keywords
Virtual Reality, VR Classrooms, Online Education, Remote Learning, COVID-19

CCS Concepts
•Human-centered computing → Human computer interaction (HCI); Visualization; •Applied computing → Distance learning; •Security and privacy → Human and societal aspects of security and privacy; •Information systems → *World Wide Web; Information retrieval;*

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INTRODUCTION
In March 2020 all U.S. public school buildings, as well as many colleges and universities, were closed to in-person attendance. By May, remote learning had become commonplace with the end to be determined [4]. The rapid pivot from in-person to online learning highlighted the underpreparedness of schools for a virtual learning environment [1, 11]. Initially, the challenges were focused on getting the technology in place for institutions, instructors, and learners [12]. Even with the technology in place, remote learning in virtual classrooms highlighted the need as well as the opportunities modern technologies could contribute to facilitating engaging and successful remote learning [19]. While the COVID-19 pandemic accelerated the recognition of a lack of engaging remote learning mechanisms, the problems with regards to socializing and engagement in virtual classrooms remain.

To address these problems, our research approaches a potential solution first by a survey and analysis of what students face when encountering remote learning for the first time and identifies the gaps between virtual and in-person learning. Based on the outcomes of the user-centered research, we then developed a Virtual Reality (VR) classroom from scratch that addresses the identified issues by the users. The resulting VR classroom was tested and evaluated by users including the instructors and the students. The results highlight the possibilities of timely and secure developments of more engaging classroom technologies which are the next steps in this research.

RELATED WORK
Recently, many industrial organizations have enhanced the quality of AR/VR devices and implemented them in our daily lives with devices such as Oculus Rift, Unity, Google Cardboard, HTC Vive, and others [9, 2, 7]. VR creates computer-generated simulations impacting several areas such as entertainment, retail, interior design, urban planning, real estate, tourism, education, manufacturing, marketing, and healthcare have adopted the use of AR/VR [3]. Along these lines, research has shown that VR poses several opportunities in virtual classrooms. It is also noted that people remember 20%

of what they hear, yet remember 90% of what they experience including experiences in simulations [8]. VR has the opportunity to simulate a classroom and create experiences in a learning context [12]. However, in the current practical applications, the majority of VR educational applications are single-user based whereas the monetary significantly better-funded entertainment industry has been able to implement multi-user based VR applications [14]. It is important to implement these strategies for enhancing the learning experience of students.

Proposing a Virtual Reality Classroom

In a systematic literature review by Noah and Das, they noted that given prior studies, it is hypothesized that the VR Classroom will score higher than Zoom in all aspects for learning outcomes, collaboration outcomes, and immersion outcomes (sense of presence) [12]. Another review of current VR classroom designs noted that "a creative virtual classroom enabled by VR technology will inevitably impact online course delivery to the extent that it might foundationally transform the future classrooms" [5]. A nationwide survey of over 1,000 K-12 teachers found that only 2% of teachers had used VR in their classrooms, but 60% would be interested in including it [21]. Notably, over 80% of teachers surveyed stated that it was a challenge to keep students engaged in the curriculum using current technologies and that the use of VR could improve learning outcomes, based on increased student motivation, a better understanding of learning concepts, and greater collaboration between students [18]. Thus the presented work here focuses on closing the gap on current limitations in students collaborations by using VR technology to facilitate interactions in virtual classrooms.

METHODOLOGY

To understand the problems students face in an all-virtual classroom and develop potential VR-based solutions, we first surveyed students at the educational institution about their experiences while taking virtual classes. Based on this assessment, we developed a Virtual Reality Prototype that aimed to addresses the main concerns. The prototype was tested by current students at the university and evaluated for how it enables collaborations in a virtual classroom.

Survey Design

To understand the problems students face in an all-virtual classroom and develop potential VR-based solutions, we first surveyed students at an educational institution. We asked 50 students 22 questions about their perceptions of virtual learning and their preferences over in-person learning. The questions targeted their learning outcomes, in-classroom collaborations, and their immersion in the virtual classrooms which was at the time taking place via video teleconferencing. The study was approved by the ethical review board.

Prototype Design

Based on the survey results, the design of the VR classroom prototype focused on enabling the aspects of learning outcomes, collaboration, and immersion to a greater extent than a traditional virtual classroom. Notable features of the VR classroom prototype include:

- **Player Representation:** Players are represented by avatars with their names appearing above their avatars' heads. Avatar movements will be synchronized with the player's equipment.

- **Multiplayer Network Synchronization:** Multiple players reside in the same VR space and can see other players in the same space in real-time. Movements are synchronized across the network that all other players see the same movement with minimal lag time.

- **360 Degree Audio Transmission:** Players can communicate with each other via their VR headsets in a way that if, for example, a speaker is sitting on the left side of a listener, the sound will be transmitted through the left side of the listener's VR headphones to simulate real-life when sound is coming in more strongly through their left ear.

- **Improved Ability to See Everyone at Once:** Avatar sizes are standardized and their quality is not dependent upon their user. Users can maintain the confidentiality of a virtual classroom (e.g. not showing their actual face), while still having a virtual presence (e.g. the avatar's body) to peers and the instructor.

- **Referencing Real Classrooms:** The desire for more realistic feeling virtual classrooms led to implementing one-on-one conversations, asking for help, forming breakout groups, moving around the classroom, interacting with and manipulating objects in the VR prototype, simulating physical classrooms.

Virtual Reality System

The VR classroom prototype was developed using the HTC VIVE Virtual Reality System [13]. It includes a head-mounted display (VIVE Headset) and handheld controllers (VIVE Controllers). For each user, this equipment was required to fully participate in the classroom prototype. The headset uses "room-scale" tracking technology that allows users to move in a 3D space and use the motion-tracked handheld controllers to interact with the environment. The operating system used was SteamVR running on Microsoft Windows [13]. The VR classroom prototype was developed using the Unity game engine and C# scripts. Additional resources were SteamVR, the XR Interaction Toolkit, PUN 2, and Voice for PUN 2. SteamVR is a Unity plugin that manages three central aspects for developers: loading 3D models for VR controllers, handling input from those controllers, and estimating what hands will look like while using those controllers. This was used to update avatar movements and register when a player is attempting to grab an object or teleport within the scene [16].

RESULTS

Survey: Online vs. In-Person Learning

50 students responded to the survey (23 female, 3 did not answer) Six students reported to be undergraduate and have not taken in-person classes at the University, 21 were undergraduate that previously have taken classes on campus, and 22 were

graduate students, one participant did not answer. The average age was reported as $M_{age} = 25.17$ ($SD_{age} = 8.15$), with a median age of 21.

Learning Outcomes

The survey identified that between learning in-person and learning virtually, learning outcomes are improved for students when occurring in-person. When asked: *What is your level of learning in traditional, virtual classrooms as compared to traditional, physical classrooms?*, 64% of respondents reported that they learn much better or slightly better in physical classrooms. When asked about the level of engagement, 74% of respondents reported that they are more engaged when a class is in a physical classroom. Together the responses suggest that students rate their learning outcomes in person higher as compared to virtual classrooms.

Collaboration Outcomes

The survey outcomes suggest that the ability to collaborate with peers is improved when students are in-person. When asked about their overall satisfaction with collaborations with peers, 56% of respondents reported that they are very dissatisfied or dissatisfied with not being able to collaborate with their peers in virtual classrooms. The frequency of one-on-one side conversations with their peers in class was reported by 65.31% of respondents to be significantly higher in physical classrooms. Similar, half the respondents were 'dissatisfied' or 'very dissatisfied' with working in groups in virtual classrooms, and not a single person reported to be 'very satisfied with working in groups. 64% of respondents reported that they would prefer group work in a physical classroom if possible. The responses suggest that collaboration outcomes are improved in-person compared to virtual classrooms. The ability for collaboration and increased frequency of one-on-one conversations with peers seemed to be a desired feature that is not available in current traditional virtual classrooms.

Immersion Outcomes

The sense of immersion in a classroom is rated stronger for students when in-person. 58% Students reported that a virtual classroom feels completely different from a real, physical classroom on campus. More strongly, 70% reported that the quality of interactions with the instructor is significantly better in physical classrooms and 90% rated the interactions with peers as better in a physical classroom. These responses strongly suggest that the sense of immersion in an educational atmosphere and the quality of social interactions is higher in-person than in virtual classrooms.

Prototype Testing: Zoom vs. Virtual Reality Classrooms

The meta-analysis found that when learning tasks were declarative, elaborate explanation type of feedback is more effective. This may be due to students needing detailed instruction or information to complete a task, which is based on factual knowledge [10]. The lecture material requires factual knowledge and is declarative so that is why detailed information will be provided to the students, followed by discussion, and then additional information is based on the discussion points to help students to complete the quiz questions.

To assess the Virtual Reality Classroom prototype, we conducted a case study with three participants. All participants were students of Computer Science at the educational institution. It was originally planned to conduct a study with a larger participant count, however, local COVID restrictions did not permit access to the facilities and hardware necessary at the time. The case study compared a control condition (video conference lecture) to a VR classroom lecture.

All three participants were the institute's students. One is a first-year undergraduate student with no in-person/on-campus classroom experience. The second is a third-year undergraduate student with in-person/on-campus and remote/virtual classroom experience. The third is a graduate student with in-person/on-campus and remote/virtual classroom experience. Each participant was presented with a lecture on linear regression for supervised learning in Machine Learning via video conference and lectures on decision trees for supervised learning in Machine Learning via the VR Classroom prototype. In both conditions, the experimental design followed the same procedure. To assess potential prior knowledge, participants completed a pre-quiz. This was followed by the lecture, a breakout group. a class discussion, and a post-quiz on the topic of the lecture. The topics were chosen as students would very likely not have encountered advanced machine learning techniques in their education and they were complicated enough to assess learning outcomes. The post-quiz contained questions that participants only were able to answer if they participated in the class discussion.

DISCUSSION

The most frequent challenge encountered during the implementation phase of the project was an incompatibility between the SteamVR plugin and XR Interaction Toolkit. The VR Classroom was developed using the Unity Game Engine, which, at the end of January 2020, released version 2019.3 where it fundamentally changed its input system. Previously, the old input system checked for input from different devices every frame to determine whether players took an action. However, the new input system separates device input from code actions. This means that only the actions that the players trigger need to be handled. Therefore, information about the device the player is using or the specific button they are clicking is not needed. Along with this new input system, the 2019.3 version of Unity also deprecated support for the built-in VR support, including for OpenVR. OpenVR was Valve's application programming interface for SteamVR. This was replaced by a new modular XR Plugin system. In building this new system, Unity officially worked with six XR platforms: Apple's ARKit, Google's ARCore, Microsoft's HoloLens & WMR, Magic Leap, Oculus, and PlayStation VR [15].

Support for these officially supported platforms can be enabled very easily and is fully supported by Unity. Moreover, Unity is directly working with these platforms on deep platform integration, improvements to the engine, and optimizations to the XR tech stack for the platforms. Unity also allows third parties to write their plugins, such as Valve's SteamVR plugin. When this 2019.3 version was released, Valve was working on a plugin for OpenVR, which would be shipped separately from Unity by Valve. This plugin is available now as "OpenVR Unity XR Plugin" on the GitHub page for Valve Software. This package provides OpenVR rendering to Unity XR, with the necessary SDK libraries for users to build applications that work with the OpenVR runtime. The OpenVR XR Plugin gives you access to rendering on all major VR devices through one interface. It offers explicit support for the HTC Vive, HTC Vive Cosmos, Oculus Rift, Oculus Rift S, Oculus Quest (Link), Windows Mixed Reality, and Valve Index [20].

Unfortunately, this is a Beta version, and Valve warns that developers should not release titles with it just yet. Games developed with this plugin cannot create OpenVR actions meaning players cannot use SteamVR's built-in system for remapping controls, nor can developers have access to the SteamVR Skeletal Input API. It seems, for the time being, Valve's SteamVR plugin, even with the OpenVR addition, and Unity's new input system are relatively incompatible. We hope that future releases of this software will help fix the compatibility issues that we encountered.

The following series of events serves to explain how this incompatibility issue was resolved.

1. First, a Unity project was developed using the new XR Interaction Toolkit. This utilizes the new input system and is a robust package that simplifies the coding needed to receive input from the controllers and head-mounted display camera. Unfortunately, without including SteamVR, no controller or HMD input was received so the game was static, with nothing happening because the hardware was not properly tracking.

2. The SteamVR plugin was included in the project, which allowed for setting up the hardware with ease. The controller tracking was smooth and the scene updated properly as the HMD moved. Unfortunately, SteamVR is not officially supported by the XR Interaction Toolkit [15]. This was made very clear by the fact that, still, no input was being received by the controllers or HMDs, so very little could be accomplished within the VR Classroom, movement-wise.

3. The OpenVR package, in Beta, was added in an attempt to reconcile the incompatibilities of SteamVR with the XR Interaction Toolkit. Unfortunately, it was highly evident that this was a Beta version [15]. The controller tracking was extremely shaky, making it near impossible to teleport or interact with objects because the controller location was not registering properly, so it often appeared far away or would fly out of control randomly. It became clear that the reliability of the tracking controller and camera input was low, and therefore not ideal for the VR Classroom prototype.

4. Since the XR Interaction Toolkit was not ideal for our use case we instead turned to the SteamVR plugin, which comes with a SteamVR player prefab. This prefab was a character controller, with SteamVR components and scripts for controlling the camera and controllers. The controllers were incredibly responsive and interactions with objects and teleportation were easily supported. The setup of the scene was dramatically different than the XR Interaction Toolkit way though. This proved to be a critical problem because, though the SteamVR player prefab was perfect for a single-person game, it does not work for multiplayer games. Multiple errors arose because the scene had multiple cameras tracking and input from one controller as "The Player class acts like a singleton which means there should only be one Player object in the scene" [17].

5. At this point, the only choice was to go back to using the XR Interaction Toolkit, which sets up the XR rig in a way that is compatible with PUN2. The problem is the controllers and camera do not properly send their input, due to the incompatibility issues that were previously mentioned. The workaround was to borrow scripts from the SteamVR player prefab (such as the camera helper script and controller components) to stitch together functional code. This was the final solution, though it's not great because none of the built-in XR Interaction Toolkit scripts work, nor do most of the SteamVR scripts, again due to the radically different ways that the two set up the XR rig and track the camera and controllers.

Future Extension of the Work: Secure VR Classrooms

The feedback from the study participants mentioned repeatedly the ability to take notes. This feedback is highly valuable as many students rely on notes and this seemed to be the largest drawback participants mentioned. With that, the ability to take notes is one of the highest priority changes we target for future work. Another change will be the use of lecture materials that best take advantage of the VR space and capabilities. For example, a static lecture does not leverage aspects of VR like being able to manipulate objects or move through three-dimensional space.

Virtual Reality could provide a significant addition to a student's learning experience, for example in medical training classes, flight simulations, and mechanical engineering. In addition, VR could enable new ways of teaching complicated concepts like graph theory, city planning or statics, and architecture. Current VR technology also has just started to implement tactile feedback for user actions [6]. The ability to experience textures or tactile feedback from an object could increase immersion and engagement students experience in their virtual classroom. However, a key concern with all of these planned interactions in the virtual classroom is the ability to protect the privacy and security of people interacting with the environment. To accomplish this, we will be adding authentication and authorization to the classroom to ensure that students and teachers are only admitted to classrooms to which they belong. In addition, we will be restricting voice chat and screen sharing actions between VR users such that a user has to explicitly grant permissions to another user before their voice can be heard, or before that user can see content that they wish to share.

CONCLUSION

The research and implementation presented here show initial proof of concept of utilizing VR classrooms and comparing them to current virtual classrooms. The implications of this research show that the VR classroom prototype is an effective means of increasing learning outcomes and immersion. Mixed results were found with respect to collaboration outcomes and the VR Classroom prototype, which is valuable in understanding what contributes to a positive collaborative experience and how collaboration can be ameliorated in a virtual setting. Overall, this case study offers significant insights into virtual learning pain points, developing a VR classroom environment with the HTC VIVE, and student perceptions and reactions to learning in a VR classroom.

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