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vSocial: A Cloud-based System for Social Virtual Reality Learning Environment Applications in Special Education

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Abstract Virtual Learning Environments (VLEs) are spaces designed to educate student groups remotely via online platforms. Although traditional VLEs have shown promise in educating students, they offer limited immersion that overall diminishes learning effectiveness. In this paper, we describe vSocial, a cloud-based virtual reality learning environment (VRLE) system that can be deployed over high-speed networks using the High Fidelity "social VR" platform. vSocial provides flexible control of group learning content and compliance with established VLE standards with improved immersive user experience for both instructor(s) and students. For our vSocial development, we build upon the use case of an existing special education VLE viz., iSocial that trains youth with Autism Spectrum Disorder by implementing the Social Competence Intervention (SCI) curriculum. The vSocial can be used to: (a) implement multiple learning modules using wearable VR technologies, (b) integrate cognitive state sensing devices, and (c) organize learning session data securely using web applications hosted on cloud resources. Our experiment results show that the VR mode of content delivery in vSocial better stimulates the generalization of lessons to the real world than non-VR lessons, and provides improved immersion when compared to an equivalent desktop version. Further, usability study results show that users can successfully use the web application features in vSocial for group learning activities with ease-of-use and consistency.

1 Introduction

Virtual Reality (VR) and the Internet-of-Things (IoT) are two of the fastest emerging technologies that are adopting cloud computing platforms. They direly need intelligent network services interconnecting smart edge devices and cloud/-fog resources. The convergence of VR, IoT and cloud platforms through a "social VR" paradigm offers promising new opportunities for consumer, business and government use cases in e.g., healthcare and education. For example, work in [1] used a VR environment for surgical training to increase the adoption of higher-value medical technologies and democratize access to surgical education between instructors and students. Similarly, studies in [2] use VR to allow students to learn in groups with higher engagement.

In social VR, the real-world smart objects are integrated with virtual world objects (user avatars) to create virtual environments. In addition, the objects or entities in the environment can interact in a real-time manner with each other [3], [4], [5]. To increase the user engagement effectively, real-time IoT applications (e.g., public safety in smart cities) integrate VRLEs for disaster management and damage containment [6], [7], [8]. The social VRLE systems render immersive content from the network-connected IoT devices to the users [9] in order to enhance human cognition in several subjects i.e., psychology and physiology [10].

The motivation to develop Virtual Reality Learning Environments (VRLEs) comes from the limitations in using traditional online learning platforms i.e., Virtual Learning Environments (VLEs). VLEs comprise of a collection of integrated tools for management of online learning that provide benefits such as: (i) ability to handle geographical separation challenges amongst the participants, (ii) facilitate continuous interaction between instructors and students, (iii) and web-based tools to monitor student progress and provide immediate feedback.

An exemplar VLE can be found in iSocial [11], a desktop application which trains students with Autism Spectrum Disorder (ASD) [12] to improve their social competencies by enabling social interaction in a virtual world. Youth with ASD exhibit a range of conditions characterized by chal-

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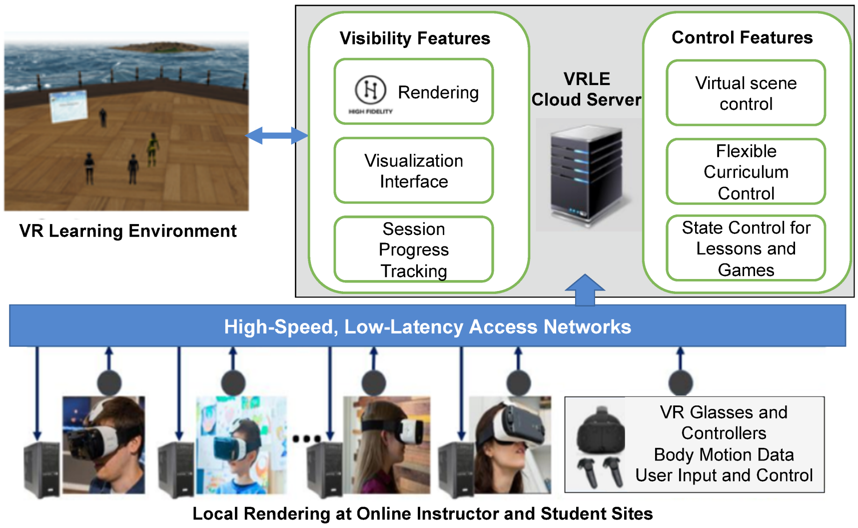


Fig. 1: Illustration of a cloud-based VRLE deployed across high-speed, low-latency network sites for online instructor-driven lessons and games content delivery using the High Fidelity 'social VR' platform.

lenges with social skills, repetitive behaviors, speech and nonverbal communication, as well as by unique strengths and differences. Some of the learning behaviors associated with ASD include delayed learning abilities, difficulty making eye contact or carrying a conversation, and other poor motor skills and sensory sensitivities. Using VLEs presents several limitations for online social training in special education courses. Firstly, VLEs do not effectively allow the generalization of knowledge and skills learning in the virtual space into the real world. Studies such as [13] suggest that effective generalization depends on how well the VLEs mimics the real-world in terms of visual presentation and user experience. Other VLE limitations include avatars not representing the user movement or appearance, and a rigid back-end that limits the instructors' ability to quickly make changes to the lessons.

In this paper, we describe a cloud-based VRLE system viz., vSocial that overcomes the above VLE limitations, which include: (a) the lack of effective generalization of acquiring knowledge and skills, and (b) the lack of immersiveness in learning - for delivering Social Competence Intervention curriculum for students with ASD. Table 1 shows the broad differences between VLE and VRLE systems in terms of various technical features. The architecture of our vSocial system is shown in Figure 1 that uses the High Fidelity [14] "social VR" platform. High Fidelity hosts open-source client-server software for creating shared VR environments that can operate in both 'Desktop' and 'VR modes'. The VR mode is supported by multiple head-mounted display devices such as HTC Vive [15] and Oculus Rift [16]. The VRLE session meeting points are orchestrated on a cloud server, which controls the virtual scenes, curriculum and the lesson as well as game activities.

Our vSocial development efforts build upon the SCI curriculum standards in iSocial, and provide virtual classroom-like spaces for real-time immersive interaction among students and instructors. We have developed both orientation and lesson units content that can be customized by the instructors, and can be integrated within High Fidelity sessions. We have also developed web applications that interoperate with High Fidelity in order to display web pages and slide presentations as part of the learning exercises. The web applications are synchronized among multiple users and provide an instructor the capability to advance slides as the session progresses. Avatar creation in High Fidelity is supported through Blender and Morph 3D (third-party software to create and link avatars to user accounts) for increasing the students' level of involvement.

Another important web application we developed is the 'vSocial portal' that presents a session scheduling and progress visualization interface for the instructor and students/parents. The portal is hosted on the VRLE server and is built on HumHub, a social networking toolkit [17]. The portal can be used by the instructors to manage VRLE sessions i.e., session creation, initiation and tracking of students' progress over multiple VRLE sessions. It also allows instructors to track emotional states of each student during various tasks being accomplished in a session when students use EEG headband wearables such as Emotiv Insight [18] or Muse [19]. The Electroencephalographic (EEG) [20] headbands detect student brain signals and this data can be visualized in real-time in the portal in the form of classified emotions such as: frustration, relaxation, engagement, excitement, stress and focus.

To evaluate the effectiveness of vSocial for immersive education, we conducted a field test with seven college-age students. The field test included each student being randomly assigned either to a VR mode or Desktop mode (equivalent to a non-immersive VLE) to login to complete a session featuring the same content i.e., games. Post-session, each student answered a user survey with respect to their experience, mainly their engagement as well as their enjoyment levels while in the VR and Desktop modes of operation. Additionally, we conducted usability tests of the vSocial curriculum

Table 1: Comparison between iSocial (VLE) and vSocial (VRLE).

Features	**Virtual Learning Environments (e.g., iSocial)**	**Virtual Reality Learning Environments (e.g., vSocial)**
Curriculum	Social Competence Intervention	Social Competence Intervention
Target Audience	Students with ASD	Students with ASD
Client Equipment	Desktop Computer	VR Hardware
User Interaction	Keyboard and Mouse	Hand-held Controllers
Cognitive Monitoring	In-person	Muse Headset
Networking	Local, Multi-users	Remotely-networked, Multi-users
User Immersiveness	Low	High

content on youth with ASD, and the vSocial portal on 5 instructors who were asked to complete a list of tasks. Evaluation of the usability of the portal was measured by the correlation of collected Objective data (eye gaze) and Subjective data (user survey). Lastly, we conducted performance benchmarking tests to determine the good, acceptable and poor network performance baselines required to run vSocial amongst geographically remote users connected via high-speed network connections.

The main paper contributions can be summarized as follows:

- We demonstrate how to transition a VLE into a social VRLE to overcome user experience limitations in the generalization of acquiring knowledge and skills, as well as in the lack of immersiveness in learning.
- We propose a novel social VRLE architecture design to connect remote students/instructors by addressing aspects of content development for curriculum learning modules, network infrastructure and cloud-hosted web application configurations, as well as related security/privacy issues.
- We evaluate the effectiveness in using a social VRLE through a *viz.*, vSocial case study that involves delivering Social Competence Intervention to students with ASD through a usability study to compare VLE/VRLE application performance, and a network requirements characterization study to baseline the user quality of experience.

The remainder of this paper is organized as follows: Section 2 discusses prior works related to VLEs and works related to implementing VR sessions for children with ASD. Section 3 introduces iSocial and describes our vSocial approach to transform iSocial in terms of system, content and web application development. Section 4 describes the performance evaluation i.e., the vSocial usability and benchmarking experiment results. Section 5 concludes the paper.

2 Related Works

2.1 *Virtual Technologies for Improved Cognitive Training*

Several existing works are focused on investigation of implementing virtual technologies (e.g., virtual learning environments [23], virtual reality (VR) [21] and robotic systems [22]) for youth with ASD. For instance, a 3D virtual learning environment (VLE) using VR technology has been a widely used approach to create simulated environments that are coupled with well-defined learning objectives [23]. In a VLE setting, students enter a virtual world through their avatars and manipulate shared objects [24]. Benefits of using VR in VLEs have been studied in works such as [25] and [26] that documented the benefits in terms of student performance and engagement. The benefits can be attributed to the fact that many face-to-face activities rely on cues such as eye contact that can be implemented in VR.

An exemplar VLE effort can be found in the work on iSocial [11], where desktop VR technology has been successfully used for training students with ASD to improve their social competencies via social interactions in a virtual world. In a related iSocial study [27], the authors demonstrated that suitable intervention strategies can enhance learning for youth with ASD. However, the level of gesture and behavioral expressions needed for immersive learning are fairly limited in VLEs and instructors often face challenges while managing instruction in VLEs due to lack of nonverbal and para linguistic cues. Moreover, VLEs in these prior works have drawbacks in terms of navigation in the virtual environment via keyboard. Due to these reasons, VLEs offer only partial immersion for the participants and do not allow for dynamic or real-time peer to peer participation. In order to overcome these challenges, we propose a novel social VRLE architecture design in this work in order to deliver VR content, while also providing seamless interaction and immersion for the ASD students. Using our approach, we are able to analyze the emotion of the students during their participation in curriculum based activities in VRLE sessions. Further, we propose a novel reference architecture design for VRLE deployments that can enhance the instructors ability to improve cognitive capabilities of the youth with ASD.

2.2 *Social Competence Training Applications*

The works in [13], [28], [29] and [30] compare VR technologies and traditional face-to-face environments in terms of their ability to: offer efficient generalization of skills, enhance social skills, social cognition, and social functioning. For instance, authors in [31] found that VLEs are well suited for training youth with ASD because VLEs: (i) allow users to learn by making mistakes without suffering real consequences, (ii) are endlessly plastic and can be customized to different user needs, and (iii) facilitate rules and constructs of the real-world to be conveyed through experience. Moreover, authors in [34] found that analytical reasoning of ASD students improved with VR sessions focusing on emotion and social aspects.

Other works involving VR in ASD related to special education such as [35] and [36] used facial emotional expression monitoring through eye gaze and physiological signals to explore new efficient therapeutic paradigms (e.g., group interactions). Our proposed VRLE design in this paper builds upon these prior works to deliver cognition and social skills enhancement for students with ASD. Specifically, our proposed VRLE architecture connects geographically distributed instructors and students uses intelligent network services. The network services leverage high-speed networking, cloud computing and social VR technologies for targeted training tasks or teacher-led activities that follow the SCI curriculum standards. In addition, using cloud computing in vSocial provides scalability of the system for a large number of users or content, and also allows instructors to quickly make changes to lesson plans that get instantly updated on the students' side. Our evaluation of the effectiveness of vSocial involves user surveys similar to the approaches in [29] and [37] for measuring the impact of immersion level on the performance of students. We also borrow validation strategies used for measuring engagement levels when comparing VR based learning environments with traditional desktop based learning.

3 vSocial VRLE

Providing immersive Virtual Reality Learning Environments (VRLEs) provides distance education capabilities for students with ASD and allows them to participate in interactive learning for skills development with remote instructors/students. In addition, VRLEs boosts realism that allows students to generalize and transfer the knowledge and skills learned in the virtual space to the real world [32]. The vSocial VRLE overcomes the system, content and web applications challenges faced by the iSocial VLE. However, vSocial adopts the standards defined by iSocial in terms of the Social competence Intervention (SCI) curriculum that focuses on improving the social interaction and behavioral skills of youth with ASD. In the following, we first describe the vSocial system design, content development and web applications integration. Subsequently, we describe the security, privacy and safety attack concerns that arise due to the networked nature of social VR, and discuss defense mechanisms we have implemented.

3.1 vSocial System Design

The vSocial system includes various components working together as shown in Figure 2. One of the main components of the vSocial system consists of the VR rendering platform viz., High Fidelity [14]. High Fidelity is an open-source social VR platform that can run VRLEs featuring virtual worlds for remote users to explore and interact with each other and manipulate objects. It supports the latest VR headsets such as Oculus Rift [16] and the HTC Vive [15] that are equipped with VR controllers. It is developer friendly and provides options such as high scale of user presence, facial features awareness, and scriptable APIs. Up to 150 users in different geographical regions can be concurrently supported with High Fidelity assuming sufficient server-side resources are allocated. To host our vSocial domain with the relevant content that is accessible to the High Fidelity platform for public use, we use the Google Cloud Platform[42]. Specifically, we have configured a vSocial domain in a cloud instance as shown in Figure 2 that allows the High Fidelity to render our hosted vSocial VRLE content from a publicly routable IP address.

High Fidelity particularly supports modifiable 3D Audio settings, and thus attenuation coefficients can be adjusted to allow control of how audio levels diminish over distance. This in turn gives a near-realistic effect of the speaker sounding quieter, the farther they are from the listener. This feature also aids in small group activities where students may discuss privately before returning for a full-group debrief. The on-the-fly VR content rendering on the clients is based on the instantaneous user head position and body movement to achieve low-delay, smooth presentation of content on the VR headsets.

The other major component is the vSocial cloud server running on a GENI (Global Environment for Network Innovations) cloud infrastructure slice [41]. The GENI infrastructure provides open cloud APIs and is deployed at tens of sites across the world. Thus, setup of the vSocial cloud server can be automated for setup at any GENI site node location that is relatively closest to the user locations for low-latency communications. For portability reasons, the vSocial cloud server has been setup as a Docker container image [45]. The cloud server also serves as a meeting point for the social VR sessions. It hosts the vSocial portal that allows real-time collection and trends visualization of student performance including the lessons progress and the student cognition data such as the emotion states collected using EEG headsets (e.g., Muse) on the client-side.

The EEG devices detect students' brain signals and classifies the brain signals into emotions, such as focus, stress, engagement, excitement, interest and relaxation. The instructors can track these emotions while the students are in the VRLE sessions to adapt their sessions. For example, consider a scenario wherein a student participating in the VRLE session has a stress level that is higher than a pre-defined

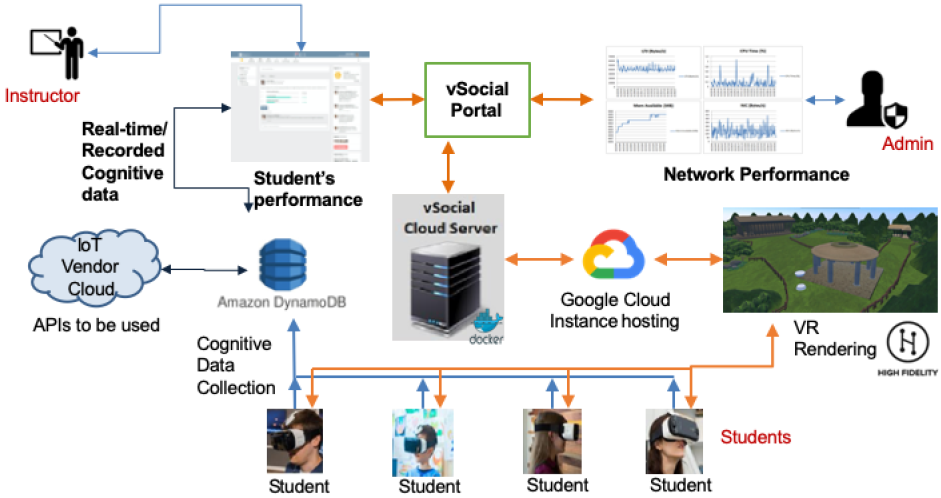


Fig. 2: vSocial system overview: vSocial cloud server runs on a GENI infrastructure slice to: (a) allow an administrator to manage VRLE sessions on High Fidelity, and (b) host the vSocial portal for instructors to monitor students' session performance including lesson progress and related emotion states.

'high' threshold. In this situation, the instructor can take that student aside and run some stress-relieving exercises; or in the worst case, the student can be taken out of the VRLE session. The EEG headband device (i.e., Muse) can be used as an add-on to the HTC Vive that is lightweight and adjustable. However, the users experience can be affected i.e., they experience a slight discomfort, due to the fixtures of multiple devices on one's head. Later in Section 4, we discuss the impact of wearing the EEG headband and the VR headset on the user's experience in our usability study.

For instructors to perform real-time data collection and analysis/visualization from the different client sites, we use Amazon DynamoDB and Kinesis web services. The portal also allows the VRLE administrator to: (a) aggregate the EEG data analysis/visualization, and (b) collect network performance data to detect any bottlenecks in the Desktop and VR modes due to misconfigurations or cyber attacks. Additionally, on the client side, the students log into the VRLE sessions through personal computers equipped with GPU hardware (e.g., GeForce GTX 970), high-speed network connectivity and VR headset connections.

3.2 vSocial Content Development

vSocial VRLE content development has been built on the iSocial VLE content standards for the Social Competence Intervention (SCI) training curriculum [11]. However, vSocial VRLE content has many transformational aspects when compared to iSocial. In the following sub-sections, we first describe the iSocial standards and then detail the various lesson units implemented in vSocial.

3.2.1 iSocial Standards

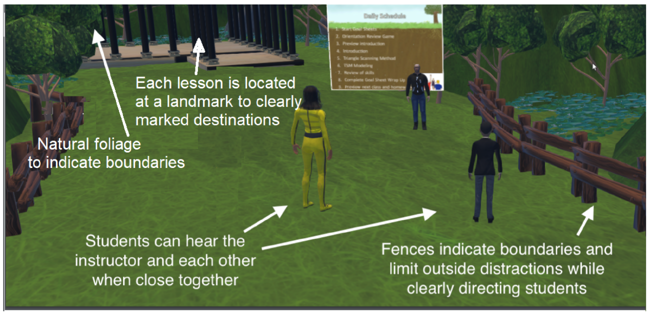
The iSocial standards provide guidance on important characteristics such as: environments built with reduced distractions, realistic avatars and guiding indicators to direct movement. iSocial development for over ten years led to one of the first Social Competence Intervention (SCI) courses based on a framework of Cognitive Behavioral Intervention (CBI) and Applied Behavior Analysis (ABA) for youth with ASD aged 11-14 years. The iSocial implementation of the SCI curriculum included different units, targeting different social skill sets shown in Table 2 and following a consistent structure of: (i) reviewing a previously learned skill and introducing a new skill in an instructional and group discussion format, (ii) skill modeling, (iii) opportunities to practice the skill in structured and naturalistic activities, and (iv) some type of closing activity or review.

iSocial was developed as a 3D VLE that allowed for practice of social competence for individuals with ASD via the SCI curriculum in a face-to-face small group setting. One of the main features of iSocial was 'social orthotics', a feature wherein the focus is on building an environment and mechanisms within the environment that are purposefully social when being social cannot be taken for granted. Consequently, the goal of social orthotics is to enable learners to engage in effective social practice which they do not have full competence. Social orthotics was implemented in iSocial via 3 applications: iTalk, iFocus and iGroup.

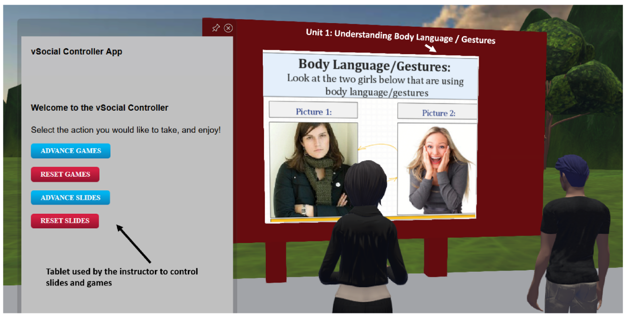
The iTalk application provided an interface for learners to force rules of conversation such as proper turn-taking, maintaining appropriate volume and tone of voice. The iFocus application provided visual cues for the instructor to indicate what is being referenced, such as using a virtual laser pointer or shaking or moving the objects. The iGroup application provided features for group management by the instructor. For example, it provided a circle or a pod on the floor indicating where the group or the user should congregate. The circle could change color when the user walks

Table 2: SCI curriculum constructs within units aimed at development of targeted skill sets.

Curricular Construct	Targeted Skill Sets
Recognition of facial expressions	The ability to interpret facial cues to identify emotional labels and analyze contextual variables about mental states
Sharing ideas with others	The ability to identify and apply the roles of the speaker and listener in a conversation
Turn taking in conversations	The ability to recognize and apply skills involved in conversational reciprocity (e.g., initiating, maintaining and concluding conversations)
Recognizing feeling and emotions	The ability to identify and interpret contextual variables for emotional recognition across perspectives and analysis of emotional variance
Problem solving	The ability to react to stress appropriately, identify problem situations and determine appropriate means to respond to situations



(a) VRLE session in-progress wherein the instructor uses a slide show to train two students.



(b) Instructor uses a Tablet interface for centralized control of the slides and games content during a VRLE session.

Fig. 3: Overlook of exemplar vSocial VRLE session content that is compliant with iSocial standards such as: environments built with reduced distractions, realistic avatars and guiding indicators to direct movement.

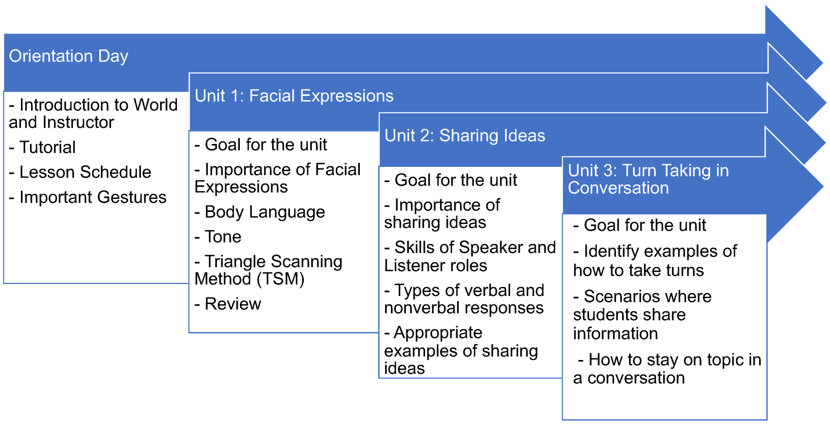
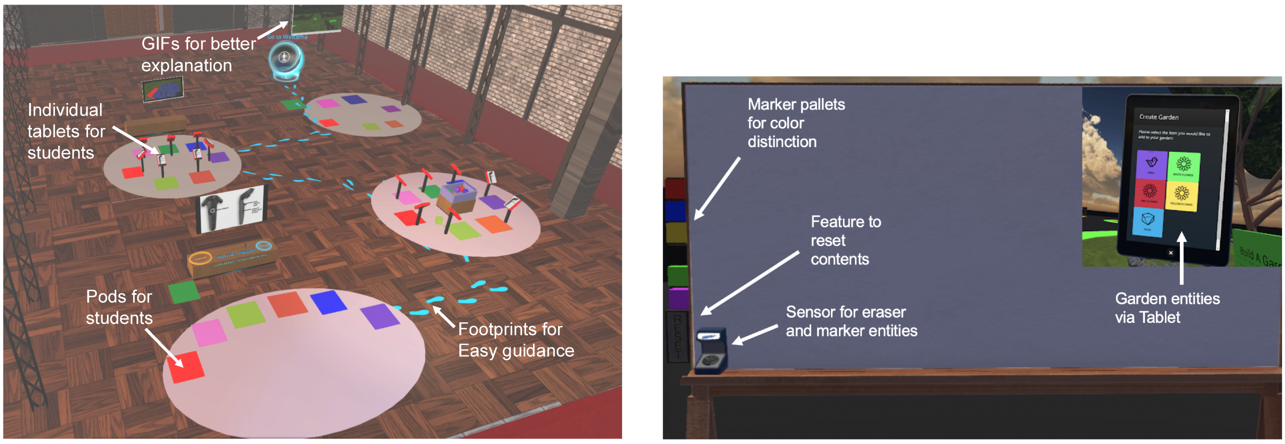


Fig. 4: iSocial's SCI curriculum units delivery sequence over several VRLE sessions; each unit features multiple lessons.

away or when a user is locked to that position. iGroup also provided automated grouping features such as "follow me" which forced all the other users to follow the instructor's avatar in the VLE sessions.

3.2.2 Implementation of the iSocial Standards in vSocial

The first step for vSocial development involved development of learning environments based on iSocial standards. Figures 3(a) and 3(b) provide an outlook of a lesson of vSocial in the VRLE, which is compliant with iSocial standards. The fundamental idea for the VRLE's layouts is to have open areas in which the students' freedom to move and interact is maintained, with natural foliage and rocks acting as clear boundaries. Each lesson of our vSocial VRLE has a unique, designated area with the theme typically reflecting the topic being taught. For example, a lesson might have the students determine individual roles on a deserted island (e.g. water collector, lookout) to practice cooperation and teamwork.



(a) Orientation Day 1 tutorial environment to train students on how to move around and pick up objects in the VRLE.

(b) Orientation Day 2 activity with a whiteboard interaction and handling a Garden Tablet application to explore the environment.

Fig. 5: Overlook of exemplar vSocial VRLE content in the Orientation Day sessions.

Each lesson also has a central area with an interactive web page, which the instructor controls, as a way of directing the students towards a common focus. Clear pathways, outlined with fences, connect different lesson parts. Teleportation portals connect related lessons and provide a quick, convenient way of traveling distances in the VRLE. Each lesson also has a unique name to facilitate direct access via teleportation.

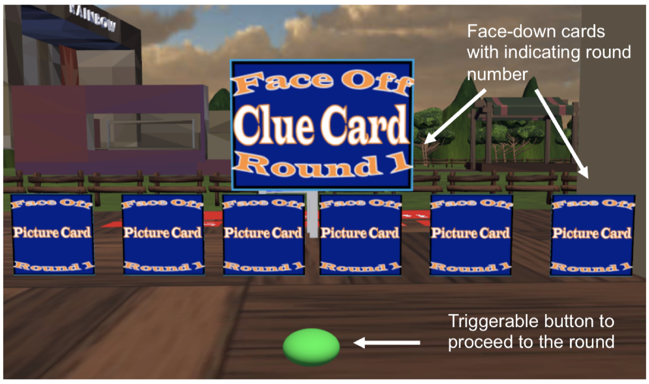
The other major vSocial development challenge was to implement the social orthotics in a VRLE setting that required using several built-in functions within High Fidelity. We implemented an iTalk-like application in vSocial on the Tablet interface in High Fidelity as shown in Figure 3(b), which helps with token-passing for proper turn-taking, maintaining appropriate volume and tone, and muting in case of many interruptions. To implement an iFocus-like application, we used in-built High Fidelity functions such that the instructor can get the students' focus on an object by pointing a virtual laser pointer and picking up the object. We also implemented an iGroup-like feature that we term as "group spaces", which keeps students within a managed space through a group circle or pod for the purpose of maintaining the students' focus during a lesson. In addition, we implemented scripts for other features such as bubbles, pop-up boxes and status bars. A bubble around a user's avatar helps students respect distance between 2 people and works such that, if a user is too close to another user's avatar, the other user's avatar disappears and both users cannot hear each other. The pop-up boxes served as notifications e.g., if instructor issued a strike or a warning to a student for misconduct, or just meters for adjusting volume. The status bars served as Token and Behavior meters for both the instructors and students to monitor during the VRLE sessions.

3.2.3 Implementation of the vSocial Curriculum

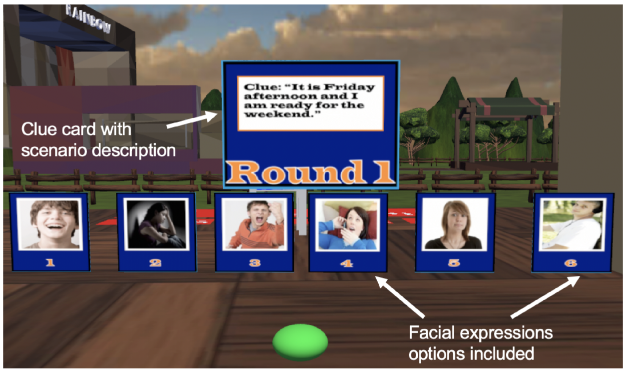
vSocial curriculum development involved creation of several units that need to be delivered to students by instructors as shown in Figure 4. Each unit focuses on different activities related to Table 2 that aims at improvement of targeted student social skills. In the following, we describe the different curriculum units developed in vSocial:

Fig. 6: The environment for Unit 1, which trains students on how to recognize facial expressions. Each section in the unit is identified by a landmark; all students stand on individual pods to deliberately restrict their movement in the VRLE when a session is in-progress.

Orientation Day: The Orientation Day acts as an introductory session for the students and can be delivered in a single day or more typically across sessions spread over two days viz., Orientation Days 1 and 2. In these sessions, students learn about the lessons schedule for each unit and participate in tutorials on how to navigate in the VRLE. Specifically, Orientation Day 1 provides an overview on what is to be expected in vSocial (e.g., controlling and moving their avatar) to learn the SCI curriculum as shown in Figure 5(a). Similarly, Orientation Day 2 introduces activities focused on getting students familiar with ways to interact with the



(a) Unit 1 Face Off activity with the face-down cards indicating the round number and a triggerable button.



(b) Face Off cards are flipped over with a scenario description and answer choice below.

Fig. 7: Illustration of a Unit 1 lesson activity involving a Face Off Game that requires students to work in a group.

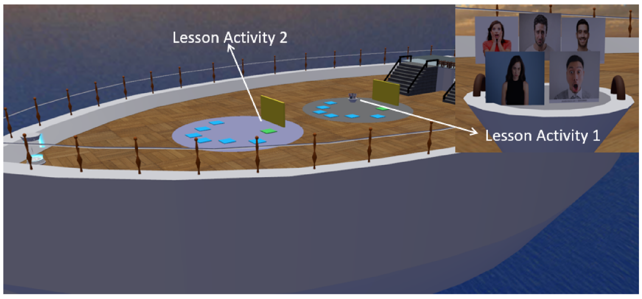


Fig. 8: Illustration showing learning group spaces for lesson activities of Unit 2.

VRLE objects (e.g., whiteboard) and features (e.g., Garden Tablet interface to identify colors, goal sheets to document personal learning goals for instructor review) in vSocial as shown in Figure 5(b).

Unit 1: Based on the SCI curriculum, Unit 1 is organized in the environment that includes near-realistic landmarks, locking pods and bounding as shown in Figure 6. In related sessions involving five lessons, students learn about recognizing facial expressions as shown in an example activity illustrated in Figures 7(a) and 7(b). In this activity, students participate in a game that has seven rounds of sample scenarios and images with people expressing unique emotions. The students must discuss with each other and identify which emotion best fits the scenario description based on their understanding of facial cues. A green button is used to progress in the game, and is triggered after the students go through the descriptions that appear on the cards with the six emotion options. The instructor reveals whether a particular group's answer is correct and also explains in-depth as to why the answer is correct/incorrect. Through the lessons, the instructor teaches crucial concepts such as the Triangle Scanning Method (a process in which students must scan the most important facial features that includes eyes, eyebrows, forehead, mouth, and tilt of head) implemented as part of the SCI curriculum.

Unit 2: Unit 2 lessons are organized on a ship as shown in Figure 8, and are mainly focused on student decision making through socialization in a group activity. Through lessons such as an island activity, students are assigned different roles such as time tracker, and manager. Based on the the mutual discussion and interactions amongst students, students have to select the things that are needed for survival on the island. Students assess the behavior of people through videos located on media boards. Through the activities performed in Unit 2 and assessment of student performance, the instructor teaches students about how to make decisions in real life situations through use of their social skills.

Unit 3: The target skill sets focus for Unit 3 deals with the capability of taking turns in conversations. Students are taught the underlying concepts of how to start, maintain, and even conclude a conversation. As shown in Figure 9, the VRLE is designed to organize learning activities for students in a city environment with skyscrapers, shopping centers, a park area and restaurants. In the lessons, students are presented different scenarios where they need to share information by conversing amongst each other. For example, a student might ask their fellow peers what their most recent favorite movie was. As the student asks the question, other students initiate the conversation, in which each student must maintain the topic by responding to the query. A few example videos of peers talking in conversations are provided to model their turn talking and idea sharing. Through this unit, instructors can also challenge students to reach their goal of improving their conversational skills in a scenario that involves creating a restaurant. In a related activity, students must share their ideas on the restaurant theme, food menu, dress code, and so on.

3.3 vSocial Web Applications

Herein, we first describe a web application that we developed in vSocial to manage and deploy VRLE content. Following this, we detail the vSocial portal we developed for monitoring and tracking VRLE sessions. Both these web ap-

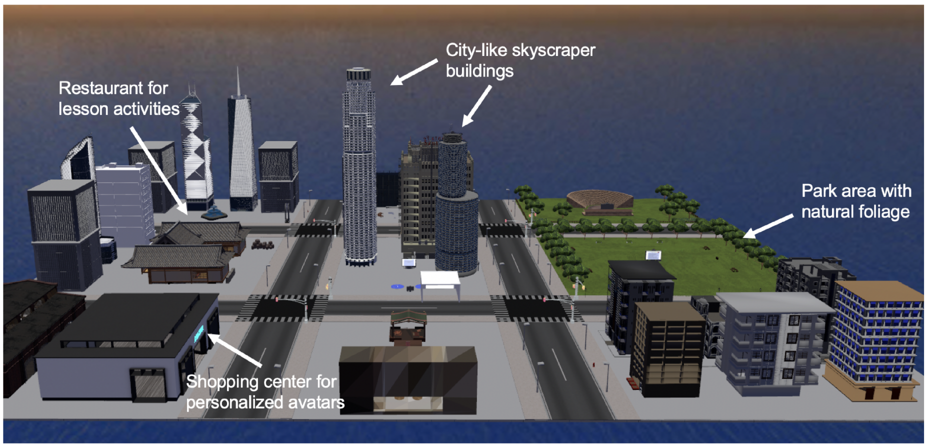


Fig. 9: An exemplar of vSocial's SCI curriculum for Unit 3, resembling a natural city environment.

plications are hosted on the cloud server and are closely integrated with High Fidelity for a seamless user experience.

3.3.1 Management and Deployment of VRLE Content

As shown in Figure 10, the instructional content (slides and games) as well as the background code are downloaded from a vSocial GitHub repository [43]. The GitHub repository is accessible to a VRLE administrator who also maintains the state of the repository. GitHub web pages are used to pull the relevant content onto the cloud server, and the instructor controls the rendering of the relevant learning content into a VRLE session on a 'web entity'. The web entity also allows instructors to create, modify, present and share slides via web pages hosted on the Slides.com web services. Through built-in functions in High Fidelity, the instructor is provided permissions to render a unique site instance for each user in a VRLE session that is commonly synchronized with other instances. Thus, the VRLE cloud server acts as a secure centralized point for instructors to display instructional content for a desired learning unit in a timely manner for all the students in the virtual worlds.

Games can also be deployed through web entities (e.g., slides, web-pages, videos) as students can perform various activities that can be hosted online and viewed by instructors. The synchronization of these web entities are maintained to allow playing of games cohesively, and also to enhance the engagement of the students through team playing. By having the capability to embed web entities in a three-dimensional VR world, instructors can easily develop content and dynamically manage changes in the curriculum delivery to students. In addition, accessing slides (a two-dimensional web entity) and interacting with familiar user interfaces through hand-held controllers (versus using a keyboard and mouse in a VLE) increases the level of student engagement and focus in a VRLE session.

3.3.2 Portal for Organizing VRLE Sessions

The vSocial Portal whose source code is openly available at [44] has been developed to integrate session creation, management and monitoring into one web-accessible location. The portal has been built using HumHub [17], an open-source social networking software. This portal can be used by the different users (instructor, student and administrator) who are a part of the management and/or use of vSocial. The instructor uses the portal to create and manage VRLE sessions, as well as monitor students' progress in various units, and their cognitive states (i.e., engagement, excitement, relaxation, stress, frustration and focus) on a session-by-session basis.

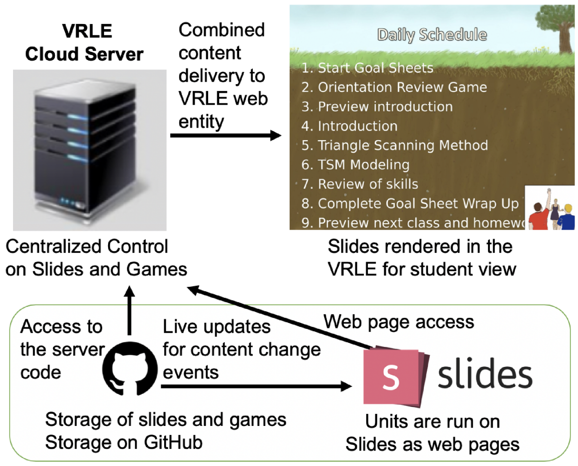
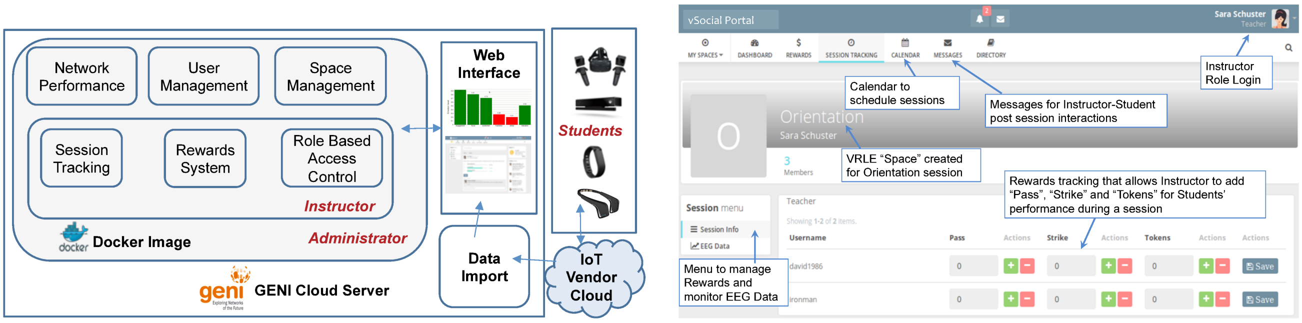


Fig. 10: Deployment of web applications on the vSocial cloud server to implement Web Entity for the instructors to control VRLE slide content in High Fidelity.

Figure 11(a) shows the components and the logical architecture of the vSocial portal. The portal related web application can be setup in a portable manner from a Docker [45] container image on any cloud infrastructure. The image is a lightweight, stand-alone, executable package of a piece of software that includes everything needed to run the portal: code, runtime, system tools, system libraries, and settings. In our vSocial experiments, we run the Docker container on



(a) vSocial Portal components for VRLE session data management. (b) An exemplar vSocial Portal screenshot for a VRLE session.

Fig. 11: vSocial Portal setup and interface for: (a) administrators to create users/spaces and monitor network/system performance, and (b) instructors to monitor and manage sessions (e.g., setup, tracking) to ensure student progress.

the cloud server in a GENI infrastructure node. The portal can pull data from an external cloud for data import (e.g., Amazon Web Services, Fitbit). Via role-based access control, the portal is configurable to allow secure access to the necessary data and tools for instructor or administrators to e.g., perform user management, setup VRLE sessions, and visualize/analyze the students' performance to provide instructors with real-time feedback in the VRLE sessions. The instructor or administrators can also can create space in the virtual worlds and invite a group of students, and track the network performance of the social VR system amongst the instructor and the students.

As shown in an exemplar portal screenshot in Figure 11(b), instructors can use the portal to assign grades or rewards based on the performance of the student in a VRLE session. We specifically developed a "Strike System", where instructors can provide the strikes and warnings to students via portal in the physical world if students engagement is low or they misbehave, and this information is accessible to the students in the virtual world in their Tablet applications. Additionally, as detailed in Section 3.1, the portal also provides instructors the ability to keep track of the cognitive states of the students wearing EEG headset such as Muse [19] on their scalps. We utilize the Muse Direct application running on the client's side that sends the EEG data using the Open Sound Control (OSC) protocol over the network to the portal for instructor access. We developed a web application on the portal to receive and write the data in real-time onto AWS DynamoDB database on the cloud or locally using Amazon DynamoDB Local. The portal then pulls the data from the database and provides analysis/visualization of the cognitive states for the instructor(s) in real-time. Mainly, tracking of the cognitive states helps the instructors to keep track of the student's stress and engagement levels, as well as to alert if a student logs off the VR world suddenly.

3.4 Security, Privacy and Safety in vSocial

Although vSocial can be used for providing special education to ASD students, failure to secure the VRLE sessions can lead to a variety of threats that can compromise the system use, and also can affect the privacy and safety of the users. In the following, we summarize the security, privacy and safety threats, and describe the design principles (e.g., hardening, diversity, principle of least privilege) to defend against them. For details on these threats and our risk assessment methods as well as design principles selection on the vulnerable components to mitigate the risk of compromise, the readers are encouraged to refer of our prior works [39] and [40].

Fig. 12: A before and after scenario showcasing the effect of DoS attack on vSocial causing a server crash

3.4.1 Security:

A typical VRLE system such as vSocial collects user data such as EEG data, student progress data, etc. making it susceptible to data tampering through unauthorized channels. Moreover, attacks such as insertion of malicious code can result in modification of session entities or data, or even changes in system configurations or access policies. To elucidate, security threats such as Distributed Denial of Service (DDoS) can compromise the availability of the system to the users as shown in Figure 12. Such threats to VRLE sessions not only compromise the availability of the system but also results in leakage of confidential data, as well as unauthorized access to VRLE content as shown in Figure 13. Unauthorized access is possible because the instructional content in a vSocial application is in a web-enabled presentation format and uses the features present in High Fidelity. Gaining *Unauthorized access* to the instructor account as shown in Figure 13 can lead to *disclosure of user information*. In addition, instructors guide the students through activities in the vSocial learning environment by having privileged access to control the learning content settings such as e.g., editing the slides, and rewarding the students based on their perfor-

Fig. 13: Example trace showing a scenario of unauthorized access to VRLE learning content.

mance. Hence, unauthorized access can lead to tampering of the learning content in vSocial, which can also negatively impact the students' learning experiences.

3.4.2 Privacy:

Threats to privacy in VRLE sessions can lead to disclosure of users' (youth with ASD) confidential information. A user privacy breach can involve an intruder entering a VRLE world with fake credentials to snoop into the virtual classroom conversations. The attacker can then disrupt an ongoing VRLE session by obstructing the view of the users in their learning sessions and can even disorient the content. Disorientation can possibly lead to a user running into a wall and getting physically hurt. In High Fidelity, user's confidential information such as virtual and physical location of the user, etc. can be disclosed that could be used to compromise user privacy as shown in Figure 14. Knowing the virtual location, attackers can disrupt the user experience of the instructors and students in the VRLE sessions. Moreover, attacks such as packet sniffing can disclose users' avatar information as well as system information as shown in Figure 15. Thus, a potential privacy breach can occur when an attacker *discloses the confidential information* obtained from the captured packets as shown in Figure 14. Furthermore, data security breaches can lead to tampering of static and transit data which allows the attacker to gain access to user credentials and real-time data import actions.

3.4.3 Safety:

In addition to security and privacy, due to highly immersive nature of VRLE sessions, user safety can also be at risk. Safety threats are termed as the factors or threats that directly impact user well-being. For instance, session takeover allows an attacker to control the VRLE content rendering, impacting user activity in a session. Moreover, any network discrepancy initiated by an attacker can cause sudden changes in VRLE rendering leading to user disorientation or even running into a wall. Threats to user safety can affect user health causing nausea, headeache, etc. Moreover, extended sessions can cause cybersickness [46] due to an individual being forced to stay in a VRLE session for an extended period of time.

3.4.4 Design Principles:

Herein, we discuss the effects we observed in applying different design principles that can mitigate the risk of Loss of Integrity (LoI) caused due to e.g., data tampering, and privacy leakage caused due to undesired disclosure of confidential user information. For selection of design principles, we followed the guidelines provided by the NIST SP800-160 related works [47] and [48] that suggest potential safeguards against security and privacy attacks involving devices and sensors connected to physical networks as part of IoT systems. We applied a combination of design principles such as hardening, diversity and principle of least privilege at different levels of abstraction to explore effective attack mitigation strategies. We found some design principles to be more effective than others, however combinations of design principles always outperformed choosing any one design principle solution. For instance, among the design principle candidates, we found: (i) {hardening, principle of least privilege} is the best design principle combination for enhancing security, and (ii) {diversity, principle of least privilege} is the best design principle combination for enhancing privacy.

4 Performance Evaluation

In this section, we first evaluate the effectiveness of the vSocial VRLE in comparison to a VLE (i.e., a Desktop application with same curriculum content but without immersiveness) in terms of the 'engagement' and 'enjoyment' metrics for education purposes. Following this, we discuss observations from our usabiity tests (i.e., user surveys) of vSocial curriculum content with youth with ASD, and with instructors using the vSocial portal, in collaboration with the Thompson Center for Autism. Lastly, we present results from benchmarking tests on High Fidelity that provide us with boundaries of Good, Acceptable and Poor (GAP) network health conditions for two important user experience metrics related to emotions i.e., frustration and engagement.

4.1 VRLE Effectiveness for Immersive Education

Qualitative tests were conducted with an expert of iSocial to obtain preliminary evaluations of our VRLE prototype. The expert was shown the VRLE with one remote instructor and two students equally distant from the instructor connected over a high-speed network. The expert concluded that: the VRLE is more immersive than Desktop, layout is more engaging and the web applications architecture in vSocial allows reuse/repurpose for many iSocial lessons.

Subjective tests for quantitative assessment were conducted with seven college-age students/subjects, comparing

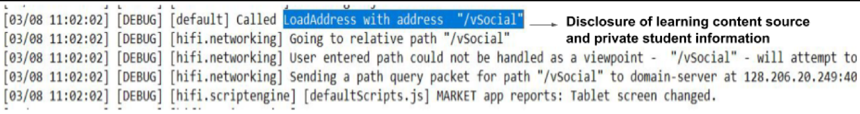


Fig. 14: Example trace showing a Privacy attack on the vSocial application.

Fig. 15: Packet Sniffing using Wireshark showing avatar and host server information getting disclosed.

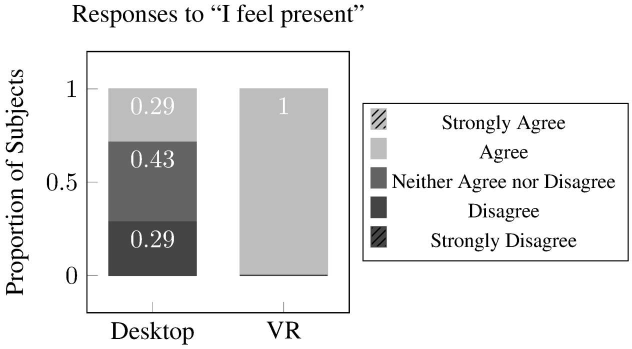


Fig. 16: Responses to Desktop and VR tests that show increased *Engagement* in VR i.e., we verified a *strong sense of user presence* in the VRLE module.

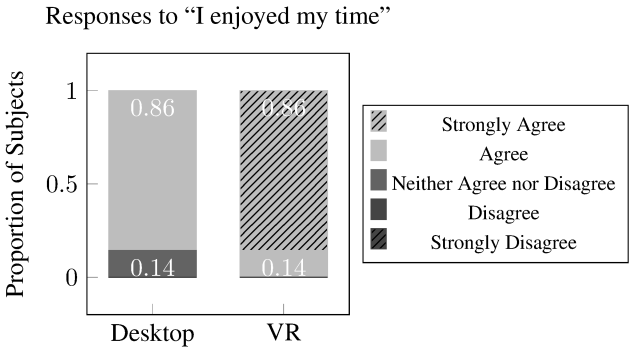


Fig. 17: Responses to Desktop and VR tests showing strong increase in *Enjoyment* in VR i.e., we verified *minimal distraction* in the VRLE module with greater *immersion* in VR.

mouse and keyboard (Desktop mode) with VR mode involving hand-held controller movement. They were randomly assigned testing desktop or VR first. Each subject was led around the environment and engaged in activities. A user survey was taken after each test. When operating on the Desktop, subjects expressed frustration with mouse and keyboard movement, as they moved slow. When in VR, the subjects found the teleportation mechanism preferable.

Additionally, subjects indicated that the VR movement was more immersive and fluid: head movement directed the avatar's orientation and hand movements were reflected on the avatar as one typically expected. Responses indicate that the subjects feel more present in VR. In fact, every subject indicated that they felt "present" in the environment in the VR mode (see Figure 16), compared to engagement in the Desktop being less than half that amount. Every subject enjoyed VR more than Desktop as show in Figure 17, indicating the greater immersion of the VRLE, and when asked, subjects unanimously stated that they preferred VR. The VR mode is not perfect; for example, about a third of the subjects felt dizzy in VR at times. Likely, this sensation was due to the subject moving their avatar with thumb-pad movement as the discomfort was corrected with use of teleportation in the VR mode.

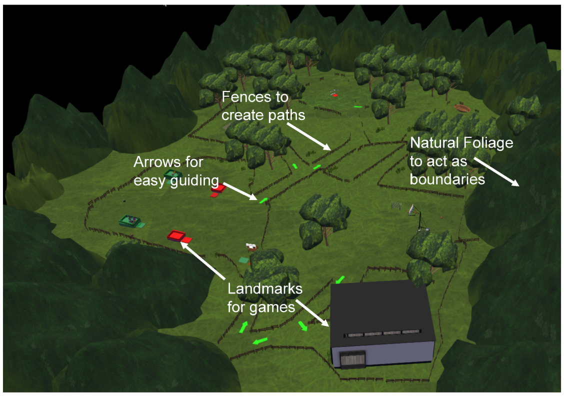


Fig. 18: Games environment implemented for the usability tests on youth with ASD involving games such as Tetherball, BasketBall and Magnetic Blocks.

4.2 vSocial Usability Tests

4.2.1 Usability Tests of vSocial Curriculum Content

To understand how usable the VRLE is for training youth with ASD, we conducted a usability test in collaboration with the Thomson Center for Autism at the University of Missouri-Columbia. The usability testing involved three students/subjects with ASD around the age groups of 11-to-14. The subject is asked to join into a VR world shown in Figure 18 with an instructor who walks the student through the

Table 3: System Usability Scale (SUS) questions used in the vSocial usability tests.

Questions	**Scale**
"I was comfortable"	Yes/No
"I enjoyed my time"	Yes/No
"I liked the games"	Yes/No
"It was easy for me to move"	Yes/No
"I was relaxed"	Yes/No
"I was distracted"	Yes/No
"I was comfortable talking to the instructor"	Yes/No
"I would like to use the system again"	Yes/No
"I liked this experience"	Yes/No

tutorial environments featuring two-player games with the student such as Tetherball, Basketball and Magnetic Blocks.

The subjects, post-session, answered a survey to document their experience in the VR world. The positive feedback we received from the students included comments that they "*enjoyed the VR*", "*liked the games*" and felt that it was "*easy to move in VR*". The instructor also felt that it was "*easy to guide the student in the VR*" and "*easy to manage the learning process*". Some negative comments we received were related to "*audio issues faced during the session*" and that the VR headset was "*very uncomfortable for the student to wear for long periods*". As we noted earlier, simultaneous wearing of the EEG headband and the VR headset is one of the factors that causes a slight discomfort to the users, which ultimately affects user experience. To alleviate the discomfort, we noted that the students require breaks in between the sessions so that they don't stand for too long and also not wear the headset for longer than 20 minutes at a time.

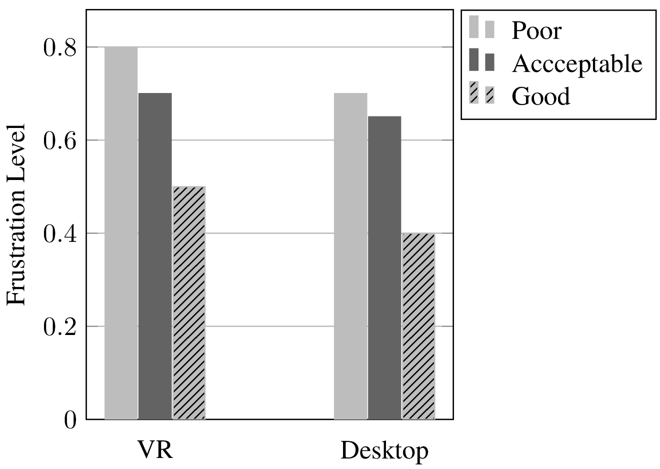


Fig. 19: Results of Avg. Frustration Level in a test session involving a game task in Desktop and VR modes under Good, Acceptable and Poor network conditions.

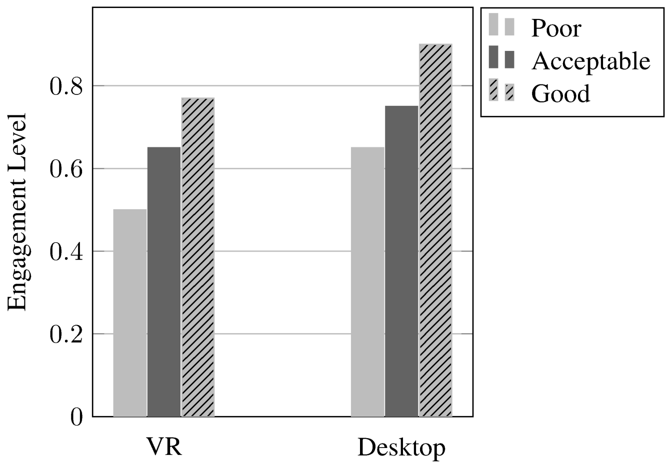


Fig. 20: Results of Avg. Engagement Level in a test session involving a game task in Desktop and VR modes under Good, Acceptable and Poor network conditions.

4.2.2 Usability Tests of vSocial Portal

Subjective tests for the quantitative assessment of the vSocial portal were conducted with 5 instructors/subjects, wherein, 3 were novice subjects and 2 subjects were familiar with the design of the portal. The 5 subjects were given a list of tasks to collaboratively complete on the portal similar to a small group session using our current vSocial setup. During the task completion, a screen capture tool recorded videos of their movements on the monitor, while an eye gaze sensing algorithm tracked the movement of their eyes. The objective data helped us understand the time taken by the subjects to complete the tasks, and if there was any bottlenecks (e.g., hesitation) in using the portal interface. The subjective data collected was a post-session user survey that was taken for each subject after they completed the test session.

The user survey was based on the 'System Usability Scale' (SUS) [49] wherein the users are asked to rate the usability of an application based on the questions shown in Table 3. The questions focused on the complexity and ease in completing tasks, the integration of various functions, need for technical help while using the application, and so on. Mainly, the responses to questions with respect to the ease-of-use and the consistency of the portal interfaces were the ones we focused in our data collection. 80% of subjects strongly agreed that the portal is easy to use, while 80% strongly disagreed that there was any inconsistency in the portal interfaces. In the end of the usability test, for each user survey response, we assigned points and the total SUS score was calculated as a percentile. Given that we had 9 SUS questions and 5 human subjects with diverse technology proficiency, we calculated the total SUS score based on a total of 45 data points collected from the usability study. A SUS score of 68 or higher is desirable to deem an application as usable. An average of the score of 75 was calculated from the 45 data points of subjective assessments that are sufficiently adequate for statistical soundness. Thus, we proved that the vSocial portal was usable and fit for the tasks it was intended to support for the instructors.

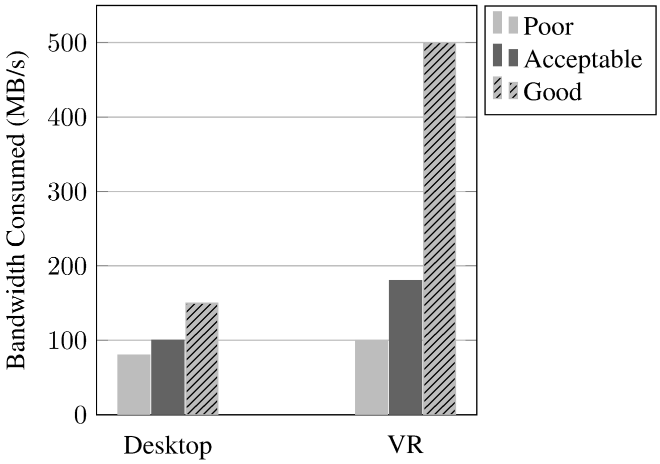


Fig. 21: Results of Avg. Bandwidth Consumed during content 'download' in a test session involving a game task in Desktop and VR modes under Good, Acceptable and Poor network conditions.

4.3 Network Needs for Satisfactory User Experience

Herein, we present results from network tests on High Fidelity for ensuring remote instructor/student communications. Firstly, we documented that setting up of vSocial with High Fidelity requires several network ports to be open on the client side. The range of forward ports that High Fidelity supports are 40100-40105, for both transmission control protocol (TCP) and user datagram protocol (UDP). Specifically, 40100 is the HTTP port used by the domain-server, and thus this port is required by nodes to get domain settings from the domain-server. Additionally, 40102 is the port used by nodes to communicate with the domain-server over UDP.

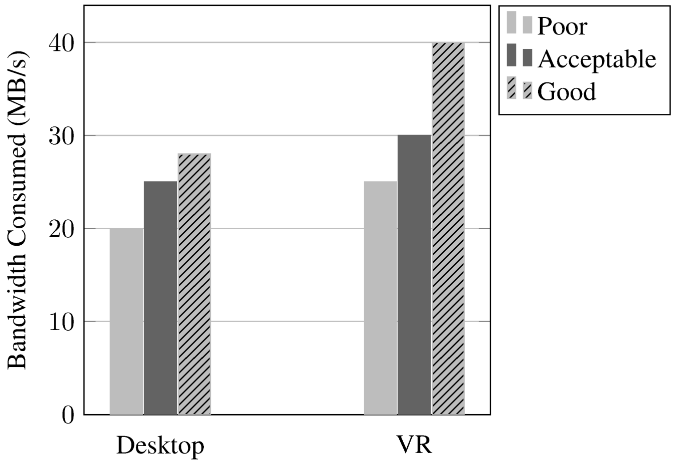


Fig. 22: Results of Avg. Bandwidth Consumed during content 'upload' in a test session involving a game task in Desktop and VR modes under Good, Acceptable and Poor network conditions.

In second set of network tests, we determined the boundaries of Good, Acceptable and Poor (GAP) network health conditions for two important user experience metrics related to emotions i.e., frustration and engagement in both the Desktop and VR modes. To emulate the GAP network conditions, we used the NetLimiter [50] tool and created rules that restrict the Download Limit (DL) and Upload Limit (UL) for High Fidelity operation. For each network health setting in either Desktop or VR mode, we collected the EEG data using the Emotiv Insight headset [18] for 4 subjects who were asked to perform simple tasks such as moving from one location to another, and interacting with another user in the environment.

Figures 16 and 17 present the differences in the frustration and engagement levels (average values) of the subjects that set the GAP levels for the network health conditions. Moreover, Figures 18 and 19 show how the user emotion GAP boundaries relate to the corresponding network bandwidth consumption differences (average values) in terms of DL and UL, respectively. Thus, we can note that High Fidelity requires a minimum of 100 KB/s of DL and 25 KB/s of UL for acceptable user satisfaction in the Desktop mode; also requires a minimum of 180 KB/s of DL and 30 KB/s of UL for acceptable user satisfaction in the VR mode. Further, we found that the render rate for the VR mode (60 MBps avg.) is higher than that of Desktop mode (45 MBps avg.) due to the need for the VR content to be dynamic, near-realistic and immersive.

5 Conclusion and Future Work

In this paper, we described vSocial, a cloud-based system for creating VRLE applications using social VR and wearable headband technologies for special education courses involving youth with ASD. vSocial is first-of-a-kind system that provides instructors and students a near-realistic, immersive VRLE to assist special education students in transferring knowledge and skills learned in virtual spaces to the real-world. It overcomes limitations in existing VLEs in terms of: (a) the lack of effective generalization of acquiring knowledge and skills, and (b) the lack of immersiveness in learning - for delivering Social Competence Intervention curriculum for students with ASD over high-speed networks. A cloud-based architecture for intelligent network services and web applications deployment in vSocial allows for extensive functionalities for content management, network performance monitoring and student progress tracking for instructors and VRLE administrators. We showed how to integrate data from EEG headbands into a vSocial portal for instructors to real-time sense, detect and track emotions of students at remote locations. Moreover, we detailed the security, privacy and safety issues that arise in vSocial deployments due to threats of DDoS attacks, unauthorized access and disclosure of confidential user information. To mitigate the impact of these threats, we suggested design principles (e.g., hardening, diversity, principle of least privilege) that can be used as defense mechanisms in vulnerable components of the vSocial system.

Further, through evaluation experiments with instructors and students, we showed that our vSocial was effective and provided high levels of engagement and enjoyment for learning. Users felt ‘present’ in the VRLE and experienced minimal distractions, owing to our implementation of SCI curriculum standards established in our prior iSocial works. User surveys also showed that youth with ASD and instructors were able to complete the special education course related tasks satisfactorily. An objective ‘System Usability Scale’ score calculation from user surveys of instructors also quantitatively confirmed the vSocial portal successfully integrates functions for VRLE session creation, as well as student performance tracking and content management during VRLE sessions. Lastly, our performance benchmarking tests provided insights on the network needs for satisfactory user experience.

Future work can be pursued to study cybersickness related aspects in a more in-depth manner and develop new applications as well as curriculum delivery techniques to improve the use efficiency of VRLEs for special education over long course periods. vSocial can also be utilized for scaling out to larger entities, such as elementary and middle school premises, or even to non-profits who provide special education services for youth to gain skills for competitive employment.

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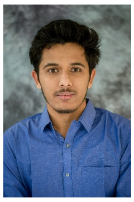

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