"Immersion is not everything!" Social vs. Collaborative Value of a Shared Virtual Environment for Design Education

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The COVID-19 global pandemic caused a spike in the demand for tools that enable us to operate remotely. While video calling solutions remain the most commonly used platform for remote learning, immersive media like Virtual Reality (VR) offer benefits to learning outcomes in an educational setting. However, immersive technologies remain less accessible to most classrooms today as compared to more traditional electronic devices like laptops and phones. In this paper we discuss the results of introducing a Shared Virtual Environment (SVE) as a tool in the curriculum of four arts and design courses across three universities. We conducted a qualitative observational study with four design courses being offered across three institutions for higher education, and collected self-reported data from questionnaires. We found that students largely preferred accessing the SVE from a 2D screen device rather than a VR device, generally using multiple channels of communication. We also found that students preferred using easier to use tools despite their lower fidelity, rather than more complex tools with a higher fidelity. We discussed the design implications for designing SVEs based on these findings, and discussed the value of immersion. We argue for a move from *social* SVEs to *collaborative* SVEs. As we move forward to an era of potentially ubiquitous use of immersive media like VR and MR, we are hopeful that the findings from this paper would help researchers design SVEs that enable their user to accomplish collaborative tasks in concert with one another.

Additional Key Words and Phrases: shared virtual environment, remote education, collaboration, online education

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1 INTRODUCTION

The COVID-19 global pandemic has caused a spike in the demand for tools that enable us to operate remotely. Video conferencing tools like Microsoft Teams and Zoom have reported an unprecedented increase in their software being used for video calls in 2020, amounting to over 300% [25, 63].

Video calling solutions like Zoom and Microsoft Teams remain the most commonly used platform. However, several groups have also experimented with using shared virtual environments (SVEs) in Virtual Reality (VR) in order to facilitate remote social gatherings [24, 32]. Social VR applications such as Mozilla Hubs, AltspaceVR, AnyLand, Spatial.io, and

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Facebook Spaces have been proposed as viable choices for remote collaboration and discussion [24, 27, 32]. Immersive media like Virtual Reality (VR), Mixed Reality (MR), and eXtended Reality (XR) also offer benefits to learning outcomes in an educational setting [36]. This has shown to be particularly true for subjects like design [57].

However, immersive technologies remain less accessible to most classrooms today as compared to a laptop screen due to cost concerns [41]. While it might be feasible for institutions to acquire enough VR Head-Mounted Displays (HMDs) for instructors, it is impractical to expect all students to also have access to a VR headset at scale. Additionally, the barrier to entry for instructors to use VR content in the classroom is heightened by the level of technical expertise required in creating educational VR content, as well as managing the VR HMDs and aiding the students with troubleshooting in case of technical difficulties [48].

Virtual Environments (VE) are three-dimensional digital representations of real or imaginary worlds which allow the user the freedom to navigate the space and interact with objects within this environment [36]. Historically, these VEs have required high computing power to render, and were inaccessible to the general public. However, modern computers are powerful enough to run such VEs, and some modern VEs allow users access from multiple device types including desktop computers, laptops, phones, and VR Head-Mounted Displays (HMDs) [48]. Such a VE might be feasible to use in an educational context due to the flexibility it provides in terms of device access requirements.

The purpose of our study is to understand the ways in which students and professors interact with and use a Shared Virtual Environment (SVE) and other tools for work through the semester. Our study was motivated by the desire to understand how the features and affordances in SVEs might affect student behavior and learning in a classroom. In particular, we were interested in looking at entirely remote scenarios (rather than co-located), and wanted to explore what aspects of the SVE might be conducive to remote pedagogical practices and classroom teaching, particularly for the fields of art and design. Instead of designing our own SVE and then testing it, we observed the use of an SVE available to consumers by the participating classes.

We conducted a preliminary pilot study for part of a semester with an immersive-only SVE, and then the following semester in our primary study we studied the use of a web-based SVE in four art and design classrooms. We conducted a qualitative study with four design courses being offered across three institutions for higher education. We collected observational data remotely about the use of this technology in the classrooms. We also collected subjective questionnaire responses from the professors and students about their perception of the use of the SVE for course delivery. Through synthesizing our observations and corroborating with subjective responses to our questionnaires through the semester, we discuss design implications that should be kept in mind while designing an immersive SVE, particularly for remote learning scenarios for art and design.

We contribute to the rich literature on the use of immersive technology in educational settings by:

- identifying and discussing themes related to the use of and SVE through the course of the semester-long study: device usage, channels of communication, ease-of-use, spatial pedagoy, and communities,
- identifying the strengths and weaknesses of an immersive classroom environment as compared to video calls, and how the two might complement each other,
- identifying technological and social adaptations that emerged from platform features and limitations, and finally
- providing design suggestions for further product research and development.

In this paper, section 2 talks about some related work in the field. Section 3 introduces our materials and methods of conducting the research. Section 4 lists all the findings and results of our study. In section 5 we discuss the design implications of the findings we list in section 4. In section 6, we discuss further implications of the findings, and the role of immersion and social / collaborative aspects of an SVE. Section 7 introduces some open questions that might suggest future work, and finally section 8 concludes our paper.

2 BACKGROUND AND RELATED WORK

Virtual Reality (VR) refers to a simulated reality that is built using computers and other digital devices [26]. While VR has been around for several decades (e.g., Sutherland's *A Head-Mounted Three-Dimensional Display (1968)* [56]), the technologies that enable users to experience VR have historically been prohibitively expensive. However, the past couple of decades have seen a drop in the cost of computing resources as well as display technologies, leading to a subsequent rise in access to VR technologies. These VR technologies consist of software that renders a Virtual Environment (VE), and hardware which allows the user to access these VEs with display and interaction technologies like a 2D desktop monitor or a 3D Head-Mounted Display (HMD). The virtual environment, level of immersion, and the feeling of presence have been considered critical aspects for understanding VR [15, 29].

2.1 Virtual Environments in Education

Virtual Environments (VE) are three-dimensional digital representations of real or imaginary worlds which allow the user the freedom to navigate the space and interact with objects within this environment [36]. Researchers have wondered about the benefits of implementing VR and VEs in education at least as far back as the late 90's [2, 29]. Within educational contexts, VEs have been utilised as communication spaces [18, 42, 61], for simulation of space [5, 45, 60], and as experiential spaces that enable the user to act on the world [28, 33, 62]. Studies have found that several aspects of a VE could contribute to learning, like presence [16, 30, 33], immersion [14, 33, 44], and direct manipulation [45].

Early explorations of VEs in education primarily used low-immersion display technologies like desktop-based VR (e.g. [29]), particularly from the early-mid 90s up until 2010. Many studies have conceptualized and validated the effectiveness of desktop-based VR for learning [5, 6, 8, 31, 46, 59], particularly from desktop-based VEs that bolstered presence [8, 35, 61], student motivation [5, 29, 53], and provided agency to the learner [5, 47], irrespective of their learning style or spatial ability [1]. In extant literature, students have shown positive reactions to VEs due to the ability to move around freely in a 3D space, being able to "meet" people, and experience virtual field trips and simulated experiences [20].

2010 served as an inflection point in time for the switch from low-immersion desktop-based VR to more high-immersion forms like HMDs. The past ten years have seen a sharp rise in the research and development around immersive technology [41]. Immersive media like Virtual Reality (VR), Mixed Reality (MR), and eXtended Reality (XR) have also been found to offer benefits to learning outcomes in an educational setting [36]. This has been validated by several studies in recent years [7, 13, 28, 38, 42, 62], including learning practices using Virtual Reality [36, 40, 43, 48, 58] and Mixed Reality [57].

In terms of disciplinary impact, VEs have shown to be particularly effective for subjects like art and design [5, 28, 57]. In particular, creative activities like creating their own virtual worlds [4, 5, 8] proved to be particularly effective learning experiences by virtue of being placed in the role of designers, pushing the students to go more in depth. This effect was seen in primary school [5] as well as in higher education [9]. Studies have also shown the effectiveness of VEs in K-12 education (see reviews in [20, 36, 39, 40]), computer science (see review in [43]), natural sciences and medicine [8, 45, 62], and linguistics [22]. High immersion offered by technologies like HMDs make them particularly effective for special education needs [13, 22, 38, 40, 44].

2.2 Shared Virtual Environments in Education

In addition to single-user VEs [33, 55, 62], researchers have also explored collaborative learning spaces with the use of Shared Virtual Environments (SVEs) [5, 8, 59]. SVEs are virtual environments that more than one user can inhabit simultaneously. These users are typically represented by virtual representations called avatars [18], which could be in humanoid (e.g., [5, 61]) or non-humanoid (e.g. [18]) forms. Such avatars may help establish a feeling of co-presence and social presence within an SVE by facilitating social encounters [18] and enabling the users to share non-verbal cues [61].

Several SVEs have been used by researchers to study their effect on learning. Early SVEs relied on 2D displays connected to desktops (e.g. INVITE, C-VISions, ActiveWorlds, Second Life). Several studies conducted using these desktop-based SVEs note the value of being virtually co-located with other learners, where socialization serves as a way for knowledge construction [6, 8, 23, 31], collaboration [3, 21, 59], and inspiration [5, 50, 61].

Again, the past five years have seen a rise in the number of immersive SVEs available for use not only to researchers but to the general public as well (e.g. Google Expeditions, AltSpaceVR, RecRoom, VRChat, Mozilla Hubs). However, a very small subset of these SVEs allow the user to access them through multiple form factors, i.e. through a desktop interface as well as an HMD. Consequently, even though these mixed form-factor SVEs show promise for use in educational contexts [48], few recent studies recount their use for learning.

Both low-immersion desktop-based VR as well as high-immersion HMD-based VR have shown promise for educational contexts. However, few SVEs allow the user to switch between low- and high-immersion systems when accessing the VE, and few studies exist that explore their use in educational contexts. Our study fills this gap in the literature.

2.3 Role of Presence and Immersion in Virtual Environments for Learning

Immersion and presence have been argued to be two of the most important constructs within the study of Virtual Environments [18]. Even though these terms are often erroneously used interchangeably, they represent distinct concepts. Immersion refers to the objective level of sensory fidelity that the VR technology being used provides the user [10]. Being a sole function of the VR technology, immersion does not depend on the psychological response of the user. On the other hand, presence is a multidimensional construct relating the psychological response of the user within the VE to their feeling of: (1) "being there" within the VE (physical presence or telepresence: [54]), (2) "being together with others" (co-presence [49, 51]), or (3) the ability of developing interpersonal relationships over time (social presence: [37]).

Immersion is generally positively associated with learning [33, 44]. However, these results should be considered within the context of the VE and the task at hand. For instance, immersion is positively associated with spatial learning and understanding [10, 44]. However, in simpler visualizations that are easier to understand, low-immersion systems might perform as well as high-immersion systems [10]. Similarly, higher levels of immersion contribute to improved interaction task performance [10]. However, this benefit is also not found in less complex situations, where low-immersion systems also performed well [10]. Some studies found mixed results on the value of immersion on learning. For instance, immersion was found to promote procedural learning, however it did not help conceptual learning [33]. Similarly, in their empirical study of the effects of immersion on science learning, Cheng et al. found a cluster of students who experienced high learning in a low immersion scenario [14].

Presence plays an important part in VEs, in particular the feeling of co-presence and social presence in SVEs [19]. The avatars used in an SVE could contribute to the degree of co-presence felt in SVEs [17–19, 34]. The feeling of physical presence [46] and co-presence [12] have been positively associated with learning. One study reported the benefit of showing a continuous presence of the instructor and fellow students in an SVE used for learning [18].

There is also a significant body of research that has explored the relationship between immersion and presence. Generally, the more immersive a virtual environment is, the more presence users tend to experience in it [52]. Some studies have shown that low-immersion systems like desktop-based VR are also capable of producing high levels of presence in their users [35].

Overall, immersion and presence (and co-presence) generally have positive effects on the effectiveness of VEs for learning scenarios. However, immersion has been shown to be important for certain kinds of tasks, and not as relevant for others. While high-immersive systems typically enable the users to feel more present, low-immersion systems also have the capability to make their users feel present, particularly in SVEs. This confirms that current SVEs like AltSpaceVR and Mozilla Hubs that allow the user to switch from low-immersion to high-immersion access might be good candidates for use in learning contexts.

3 MATERIALS AND METHODS

We wanted to understand how an immersive Shared Virtual Environment (SVE) might be used for remote pedagogical practice and classroom teaching, particularly for the fields of art and design today. Instead of designing and testing our own SVE, we observed the use of an existing SVE by professors and students. We conducted a preliminary pilot study for part of a semester with an immersive-only SVE, and then the following semester in our primary study we studied the use of a web-based SVE in four art and design classrooms. We were particularly receptive to themes around how the students and professors used the SVE; what specific tools within and without the SVE did they employ and for what purpose; and if they accessed the SVE from an immersive VR headset or not, and why.

3.1 Pilot Study

COVID-19 forced an abrupt adoption of remote work and school. In April 2020, we conducted a short preliminary study in the "Digital Materiality" class at an American design institute in order to understand the ramifications of moving a fine arts course completely online and accessed through VR. The class had one professor and 16 undergraduate students. We used the AltSpaceVR SVE in order to provide the virtual meeting space, and developed a room that was tailored to the needs of this class. The professor and students accessed the SVE through an Oculus Go headset. We collected observational data by virtually attending a few class sessions in VR. The purpose of this short unstructured investigation was to get a sense of how students and the teacher might use the VR SVE, and indicated that an immersive remote virtual classroom held value when compared to video-call based classes. These results encouraged us to continue our investigation.

3.2 Primary Study

We conducted a qualitative study with four design courses being offered across three universities. We recruited 4 professors and 51 students. While the pilot study was centered on completely immersive system (AltSpaceVR), we realized that mandating the use of head-mounted displays for every class session was impractical. The purpose of our primary study was to explore how an SVE might practically fit into an existing design or fine arts curriculum through a longer time period (one semester). Additionally, we wanted to reveal and understand the preferential and behavioral patterns that might emerge in the way our provided SVE was used in the classrooms.

3.2.1 Sampling. We conducted the study with four fine arts and design courses. We recruited four professors (one of the professors was the same as for the pilot study) and 51 students (38 undergraduate, 11 masters, 2 PhD students, no overlap with pilot study and no student was in multiple classes) from three universities. The classes were "Digital Materiality" (15 students, mix of undergraduate and graduate students) and "Apparel Fabrics" (10 undergraduate students) in the Textiles department of an American design institute, "Interactive Media 1" (20 undergraduate students) in the Art department in an American public university, and "Understanding VR" (9 graduate students) in another American public university.

Of the 39 students that responded to our preliminary survey, 31 students reported having had participated in a remote learning class before through the use of video calling software. Every student had access to a laptop or a desktop device at home with a fast (n=27) or a slow (n=12) internet connection. 32 students reported having some (n=13) or substantial (n=19) experience in navigating a digital 3D environment like a video game on a 2D computer screen. 19 students had some (n=16) or substantial (n=3) experience with using a VR headset, but only 8 students reported having used any social VR application ("Substantial experience" n=2, "Some experience" n=6).

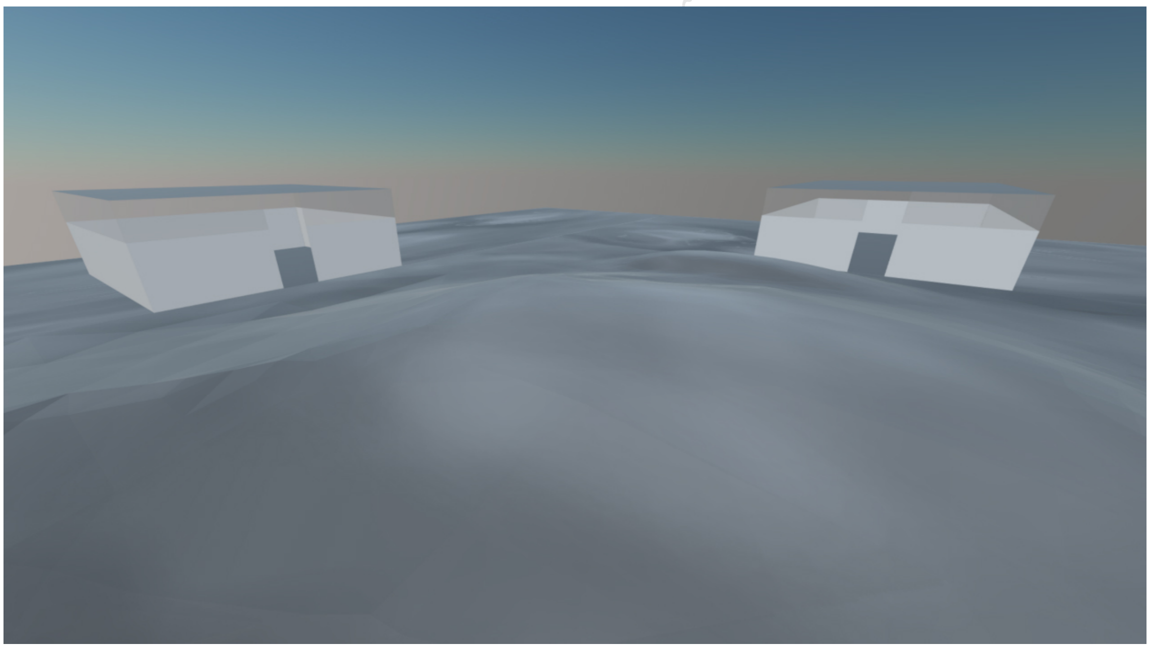

Fig. 1. The professors were provided with a simple Mozilla Hubs scene, which they were free to remix and use as they saw fit.

3.2.2 Technology implementation and support. For this study, the Mozilla Hubs web application served as the SVE. We created a simple Mozilla Hubs scene (*VR Edu Seed Space*, Figure 1) using Spoke, another web application that lets its users create scenes for Mozilla Hubs. Similarly, we also created a simple VR studio space for the students to use as a template to build their personal rooms for the duration of the class. The professors were given access to the seed space, and the students to the studio space, with the ability to "remix" or "fork" this scene (i.e., use this scene as a starting point to build on). The seed space and student studios were scaffolding tools, and their use was not mandated by us.

The professors and students were free to use the seed space or the student studios in whatever capacity they desired or needed.

We created five single-page tutorials on how to use Mozilla Hubs and provided technical support as needed. Each study participant was given an Acer Windows Mixed Reality (WMR) HMD that they could use in school IT labs, or a Lenovo Mirage Solo to use at home for the duration of the semester. We did not provide a laptop or desktop computer. We did not mandate the use of any of these devices for any class session.

3.2.3 Data collection. We employed a mixture of systematic participant observation and self-reported subjective data on professor and student perception of the use of Mozilla Hubs in the classroom context.

Participant observation. Two researchers from the research team attended the various class sessions semi-regularly over the course of the study in each university. The researchers engaged with the class minimally (eg. answering technical questions about the use of Mozilla Hubs or Spoke). We performed observation and recording of the classroom activities, particularly focusing on the behaviors, interactions, language, and social cues in the SVE during the class session. The researchers made notes, and collected still and video recordings of the virtual class sessions.

Questionnaires. Each study participant was given three questionnaires over the duration of the semester. The first was provided at the beginning, and inquired about their previous experiences with technology. The second and third surveys, administered to the students around the mid-term and after the final week of classes, aimed to gather data on social cues (eg. professor-to-student and student-to-student engagement, sense of emotional connection and effects on social relationship), as well as the technology adoption (usefulness of VR environment for classroom needs, VR HMD vs laptop ease of use and access, ease of use and customization of the SVE).

3.2.4 Data analysis. We performed an inductive thematic analysis [11] of the data collected during observation (notes and video recordings), which is grounded in the data collected rather than pre-existing themes. We continually shared and read each other's notes after each observation session and discussed them. This gave us a better idea of what kind of data it contained. These discussions informed the questions we included in the mid- and end-of-semester questionnaires.

For thematic analysis, we started with open coding observational notes and the video data. We created a time-stamped list of actions and behaviors from the video recordings, which was used for the coding exercise. For the first round of open coding we used descriptive labels, which we combined into categories in an axial coding step. Finally, through discussion amongst the researchers, we developed five latent themes [11] through our inductive thematic analysis of the data which we describe in the following section.

4 FINDINGS

We categorize our findings into five themes: device usage, communication channels, ease-of-use, spatial pedagogy, and communities. The first two themes focus on the user's choice of tooling–either a hardware device or a software communication tool–and try to understand the reasoning behind these choices. The last three themes emerged from analyzing user behavior while using the SVE in the classroom.

4.1 Device Usage: VR vs. Desktop

The SVE that we selected for this study, Mozilla Hubs, is a web-based cross-platform software that can be accessed from multiple devices, including a laptop / desktop and a VR Head-Mounted Display (HMD). The students as well as professors already had access to a computer, and everybody was provided with a VR headset. None of the professors mandated the use of VR devices by students for their class sessions. There was a clear theme in the hardware device usage for attending class sessions in Mozilla Hubs–VR HMD usage was negligible when compared with laptop usage to access the spaces. None of the students reported accessing Mozilla Hubs from immersive VR for more than 5 hours per week, whereas a majority of the students reported spending at least 6 hours per week in Mozilla Hubs on a laptop. In some class sessions we had mixed usage–some in VR, some on a laptop.

Laptop adoption was driven by several factors. One of the reasons was the barrier to entry of using a VR device to access the Hubs spaces. Most of the students and professors had never used a VR device or Mozilla Hubs before. In classes that utilized a standalone VR headset, even the process of using the VR device was perceived as a daunting task by some students. Since the classes took place remotely, expert students or the professors could not provide the level of support they might have been able to during in-person class session. Getting a Mozilla Hubs room to launch on these standalone devices was challenging, which impacted VR adoption particularly at the beginning of the semester.

In time, students felt more comfortable with the process of creating Mozilla Hubs rooms (we expand on this in "Ease of Use"). However, they encountered a performance limitation in VR–the Hubs rooms launched in standalone VR devices were less performant than their desktop counterparts. Performance in VR took a hit since many student rooms had multiple objects and every class session involved having 9-20 people in the Hubs room. This negatively impacted the user experience of using Hubs in VR. This was a reason for one of the classrooms to switch from a single virtual space with all student work to separate Hubs rooms for each student, as pointed out by Student 16 (S16):

S16 We ended up using portals instead of one classroom space. But the VR headset was still extremely laggy, most of us ended up using Mozilla Hubs on our laptops.

Some students also reported physiological reactions to using VR, including fatigue, as a reason for reducing VR usage to access Hubs:

S13 Sometimes using VR you can get a headache so its not fun to stay in too long, I switch to a monitor after a little bit.

S27 i find it very exhausting using the headset for longer than an hour.

Task performance and needs also informed VR HMD usage. Students felt that VR was best suited for tasks that either involved solo work, or sharing their in-progress work with others. It's important to clarify here that even though students felt that VR was better suited for solo work, they still did not utilize it as much due to other limitations outlined above (barrier to entry, complicated process, performance limitations). Additionally, multiple students like S8 below mentioned that when the work entailed creating assets for the Hubs rooms or other high-level work like brainstorming and ideation (rather than testing the Hubs room itself), students preferred using a desktop interface to do that. Additionally, for tasks that tended to be more collaborative (discussions, group activities, and attending a lecture), students preferred switching to a video call (Figure 2).

S8 I do find the VR mode to be better for interacting and viewing the world. Although I will always use the desktop mode for actually creating.

This usage pattern indicates that Hubs lacks tools that students could use to meaningfully contribute to creative work. Professor 4 (P4) indicated that the primary use case for Mozilla Hubs was observing, exploring, and creating the rooms. He pointed out the lack of interactivity in the Mozilla Hubs space, and how for most of these tasks using the spatial affordances of the SVE was enough. This made him question the value of overcoming technical hurdles in order to use VR.

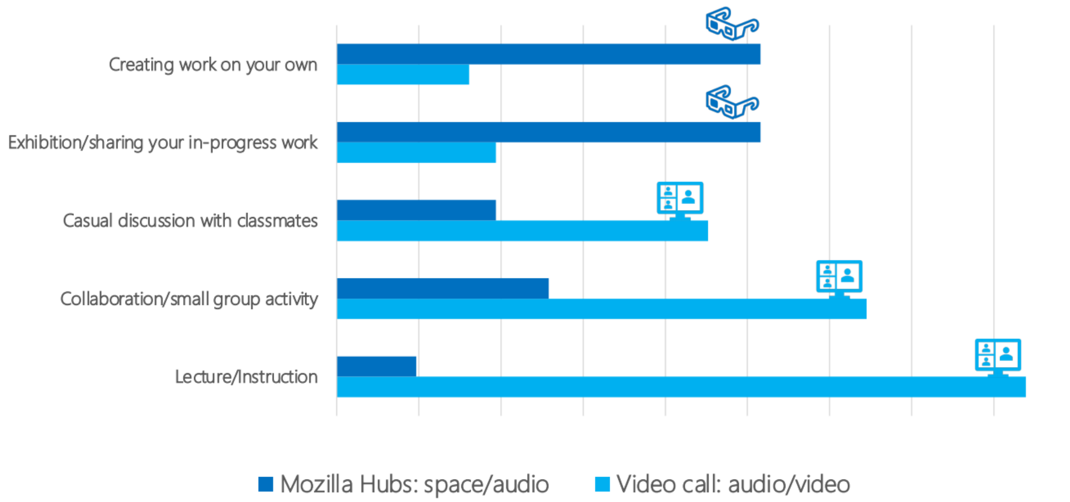

Fig. 2. Student preference for using Mozilla Hubs as opposed to video calls depended on the task they were trying to accomplish.

P4 For our purposes, we were okay using a 2D screen to access the spatial virtual environments. Immersion isn't everything!

4.2 Channels of Communication

Spatial audio proved to be crucial for a spatial navigation experience, in both VR as well as a 2D screen. However, a recurring theme in our observation of the classrooms was the inadequacy of the channels of communication offered by the SVE. In addition to the spatial audio used to communicate within the SVE, the students and professors used other channels of communication such as video communication (through Zoom or Microsoft Teams), audio (by continuing a video call in the background), and text chat (within Hubs, over SMS, in the video call chat, or over Slack or Discord groups). In these scenarios, the students and professors either had an ongoing communication channel in parallel to the SVE (most frequently, audio), switched back-and-forth between the SVE and a different channel (most frequently, text and SMS), or used a different channel of communication in addition to the SVE (sequential rather than parallel–most frequently, video calls).

4.2.1 Video communication. The means of and motivations behind the use of other channels of communication varied by class. For instance, one class preferred to convene in a video call for an introduction or presentation before transitioning to Mozilla Hubs. Their class sessions usually also ended with a transition back to video call to conclude the class. This was supported by the preference for students and professors to use video calls for both collaborative activities as well as lectures and small group discussions (Figure 2). This was particularly true for the final show-and-tell sessions where the added performance limitations of having multiple users in the SVE slowed things down. Also, once the space was crowded, it was hard to tell who was speaking–spatial audio got muddled when multiple users are occupying the same space. Video calling software typically don't implement spatial audio, however they use other visual cues to indicate the current speaker (such as highlighting a speaker's bounding box).

Another limitation of the Hubs space was the lack of congruence between the user representation in the physical space and the virtual space. For instance, when using VR, Hubs represented virtual hands in the virtual space that were mapped to the physical location of the user's hands in physical space. This allowed students to communicate body language to some extent. However, since others were unable to see a user's physical body and facial expressions, non-verbal cues like body language and emotions often got lost. This issue was exacerbated even more when students accessed the environment on their laptops, which was the prevalent way of accessing Hubs rooms. This made troubleshooting challenging for technical issues like a room not loading for a student, or network and connectivity issues. Since it was common for the groups to jump from one Hubs room to another, there was a disconnect in the channel of communication in the transition period–while the Hubs rooms were loading for the users, there was no way of knowing who might have faced trouble in transitioning to the new Hubs room. For this reason, multiple classrooms had a video call running in the background as a consistently open channel of communication, that was available even during the transition periods between Hubs rooms. Some classrooms only used this video call as a troubleshooting tool–they would keep the microphone input muted on the call, and use spatialized audio within Hubs. When they didn't see a student in the new space after a transition, they would switch to the video call to check if it were a connection issue. Otherwise, the student who was having trouble could speak up in the video call to get the attention of the professor, who could help them. Navigating to wrong rooms or incorrect links was a common occurrence that could be solved by this kind of intervention. In addition to video calls, users also used text communication over channels like SMS, chat in the video call, Slack, and Discord to communicate with each other, particularly for troubleshooting steps.

4.2.2 Audio communication. Audio and text communication culture varied by class. While spatial audio was important in establishing and experiencing the spatial nature of the Mozilla Hubs spaces, there were scenarios where the visitors either (a) did not need spatial audio, or (b) where uniform audio was more important than having spatial audio. This was often the case when the class was engaging in activities that involved more than one tasks from Figure 2. For instance, a class session involving workshopping and critiquing a student's work in an informal setting would be a combination of "sharing your in-progress work", "discussion with classmates", and sometimes "small group activity". In such cases, classes would use a standard audio channel from a video call in parallel to navigating the Hubs space. Typically, users would mute their microphones within Hubs and use the audio channel in a video call to communicate during class. However, the Hubs spaces could still have embedded audio in the space, which would be spatial. This gave rise to an interesting spatial navigation experience where the spatial navigational cues were both visual as well as aural, but social communication happened on a non-spatial channel, enabling the students to always listen to each other and the professor irrespective of where they were in the virtual space. Another benefit of having a parallel channel of audio was the consistent nature of the audio channel, as opposed to the Hubs space. The simultaneous use of audio channel in the background and the Hubs space in the foreground enabled exploration without separation during the transition phase of moving from one Hubs room to another. This usage developed because this class explored many rooms together and wanted the stability of consistent audio to keep the group together.

We found that some classrooms adopted social norms and etiquette typically employed in other remote social tools like video calling. For instance, one class mostly muted themselves in Hubs despite not using a video call simultaneously. This usage pattern is also observed in video calls where the audio is reserved for the meeting leader or event host. In this class, the students reserved the audio for either the professor, the currently presenting student, or questions during allocated QA time. We observed this usage pattern in classes that conducted the classes in a more formal manner.

However, one professor explicitly tried making the Hubs meetings more casual, and insisted that everybody unmute their audio within Hubs.

4.2.3 Text communication. In addition to video and audio, students also used text chat on various devices and software tools, such as embedded chat within Mozilla Hubs, the chat feature in video calls, sending messages over Slack or Discord if such a group was set up, or even SMS text messages.

Students used text chat within the Hubs space to troubleshoot, share links, contribute to the discussion without interrupting the presenter, give kudos to others, and to initiate room-wide communication (Figure 3). Room-wide communication, in particular, was helpful when the classes did *not* have a parallel non-spatial audio communication channel running through a video call.

Text chat in Hubs was used to augment audio, but was also used as a fall back when audio was not working. Headset users had no text chat functionality, one of several contributing factors in low headset adoption. Despite frequent use, students did not report a strong preference for Hubs text chat for casual discussion with classmates when compared to video call-based text chat.

4.3 Ease of Use

Even though the VR medium posed a high barrier to entry for most students, students found creating within Hubs to have a much low barrier to entry when using a desktop or laptop computer. This enabled the students to engage with the course content. Of 32 respondents to the third survey, 31 students across the four classes created their own Hubs room, 29 of whom used the Spoke authoring tool (a sister tool also offered by Mozilla that helps its users create custom rooms for Hubs). Students filled these spaces with a variety of content types (Figure 4) via Spoke's drag-and-drop interface. This content was either self-created (0-10 objects, n=6; 10-20 objects, n=5; 20-30 objects, n=1; more than 30 objects, n=3), or imported from content libraries built-in to Spoke (0-10 objects, n=7; 10-20 objects, n=3; 20-30 objects, n=6; more than 30 objects, n=16). For example, student 21 (S21) noted the freedom of using a digital tool to iterate, which implies a level of familiarity with the creation tool that enabled them to iterate on design concepts:

> **S21** In here you can iterate without wasting materials!

Professor 4 (P4) also mimicked this sentiment:

> **P4** The low bar to creation for the Hubs ecosystem allowed the students to create their own rooms and apply the theoretical concepts that we were learning about in normal class sessions through video calls.

This was in contrast to what we observed in our initial pilot study with AltSpaceVR, where the barrier to entry is much higher. For the pilot study, we had to develop a tailor-made scene built with the MRTK library in Unity for AltSpaceVR, and while it served as a meeting space, it did not afford customization by the professor or the students due to intricate UI controls, a steep learning curve, and many advanced options for expert users.

4.4 Spatial Pedagogy

We found that the spatial navigability and spatial audio cues present in the Hubs environment aided some learning tasks, while hampering others. The freedom to move around in a spatial environment combined with the absence of a predefined social norm of how to act in an SVE gave rise to interesting scenarios. We expand upon specific themes that align with the emergence of a new spatial pedagogy.

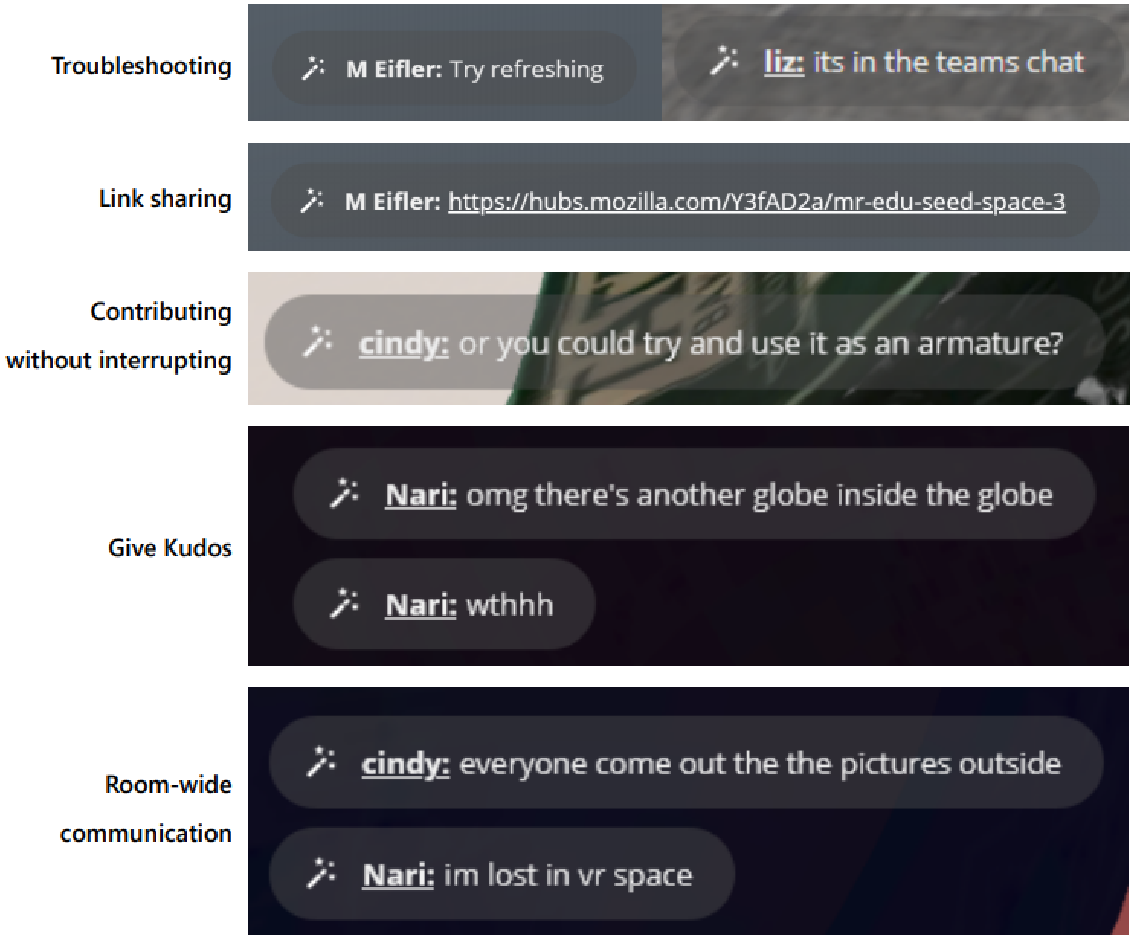

Fig. 3. Textual communication was used to fit several use cases.

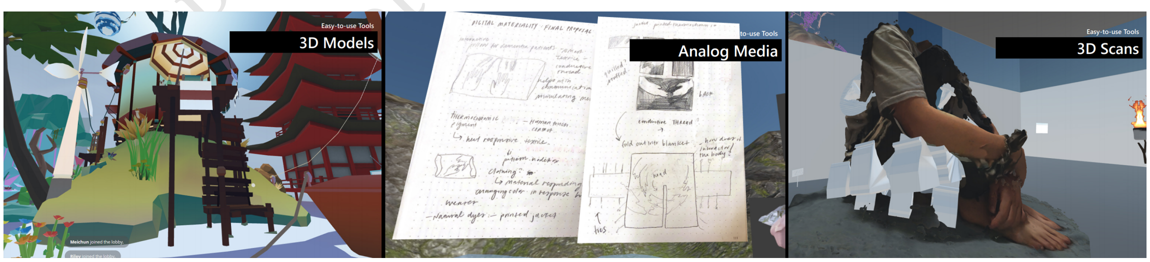

Fig. 4. Mozilla Hubs allowed the students to use and combine several kinds of media in their spaces. Shown in the figure: 3D models, (digital pictures of) analog media, and 3D scans.

4.4.1 *Creative freedom.*

The spatial nature of the SVE allowed students to create presentations utilizing various presentation styles. In particular, compared to a video call, students found that they could use this in more meaningful

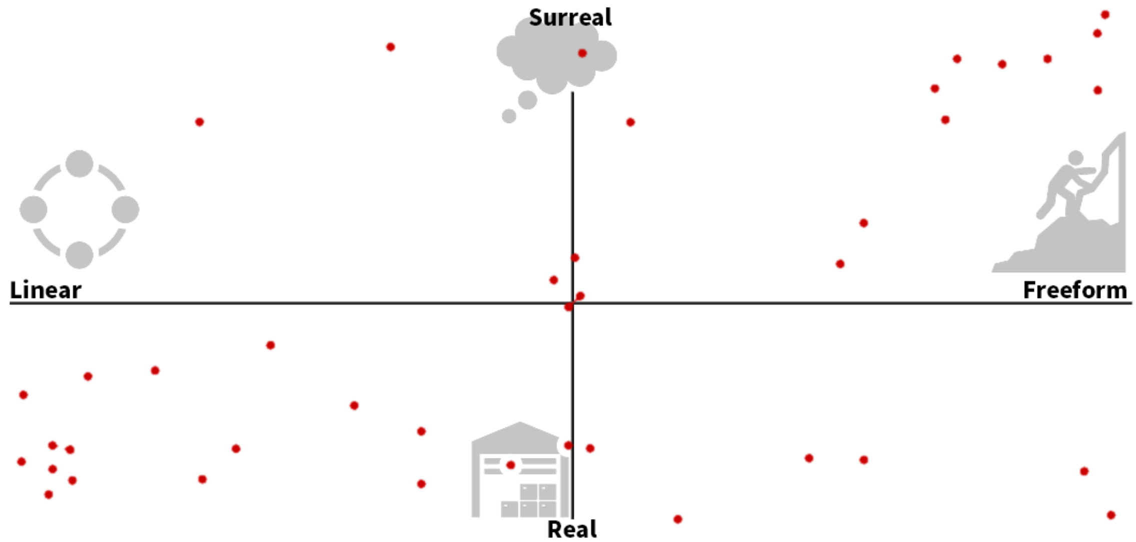

Fig. 5. Students' spatial organization strategies, depicting student rooms on a two dimensional plane defined by its level of real/surrealness on the vertical axis, and the level of free-form movement on the horizontal axis.

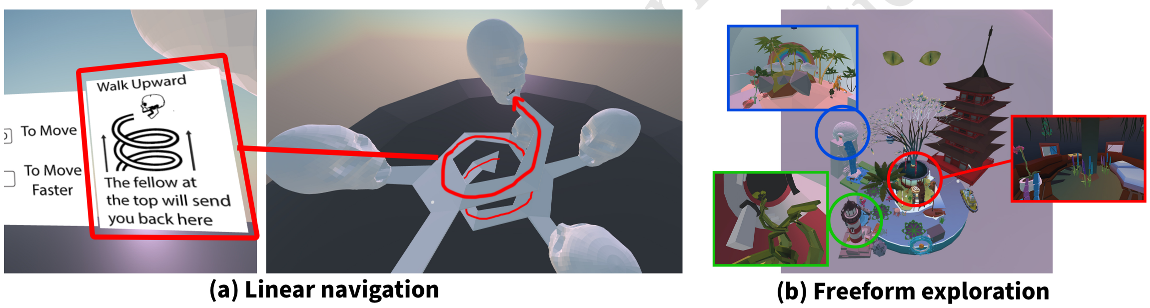

Fig. 6. Examples of navigation in student rooms: (a) shows a room with explicit instructions of how to navigate the room in a linear manner, and (b) shows a room that rewards its visitors for free-form exploration. For instance, the beanstalk inside the lighthouse (green outline), the oasis within the igloo (blue outline), and the furnished outhouse (red outline).

ways to get ideas across. Some example presentation layouts were pictures in a circle, full installations in galleries, and customized buildings and mazes. We situate the Hubs rooms created by students on a two-dimensional plane (Figure 5). The first dimension signifies the designed navigability of the room, from "linear navigation" (Figure 6(a)) to "freeform exploration" (Figure 6(b)). The second dimension places the environments on their visual similarity to "real" life, from real (Figure 7(a)) to surreal (Figure 7(b)).

In addition to the spatial layout, spatial sound also provided students additional creative freedom by offering an additional sensory modality for purposes like wayfinding. Some students used this ability to create "sound bubbles", where the user would only hear a sound within close proximity of the source. In addition to creative freedom offered to creators, spatial audio also provided social cues to the students. The combination of the spatial layout along with spatial audio made it similar in some ways to a physical gallery experience which the students might have experienced

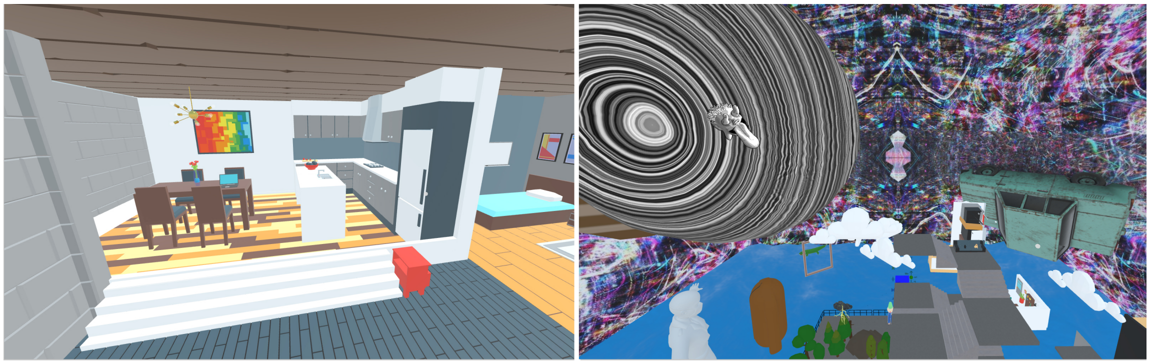

Fig. 7. Examples of levels of surreality in student rooms: (a) real, and (b) surreal.

in their in-person design or art classes. This helped the attendees develop protocols to use in the virtual classroom, loosely borrowed from protocols in physical spaces.

Professor 2 (P2) observed that students used the SVE as a creative tool for idea exploration in addition to a presentation tool:

> **P2** What started as just a sharing presenting tool, you all managed to use to make pathways through ideas.

4.4.2 Enhanced agency. In addition to creative freedom, the SVE also gave students the agency to experience others' creations the way they liked. The SVE allowed the students to have more agency in what they encountered and saw, which is different from the typically linear experience on video calls where the presenter has control over what the audience sees. The presentation of ideas and images in a non-linear format allowed for students to make choices about what to look at and in what order. Unlike in a video call, the students never had to ask to go back to a slide–they could just walk to any image or presented work that they were interested in. Different students might have different preferences for how they encounter and learn from media and art, and the spatial environment accommodated these different preferences for media consumption (eg., spending more time looking at and critiquing a piece as opposed to cycling through them quickly, going from one piece to another by the same artist in a linear fashion as opposed to jumping between works of different artists / students).

> **S13** I think that it allowed my peers to interact with my work more freely. Normally I would share my screen and go through a slide show. With the VR space, people could spend time looking at what they found most interesting and could make comments on that.

The spatial format of the SVE also gave the students the ability to control their level of social engagement. Students could join other students in a large group, in a small group, or be by themselves looking at work. Choosing how to walk around a room (and how close to be to professor, peers, and objects) enabled the students to create personal narratives and allowed for chance encounters with other peers as well as with student work, which would not be possible in a typical video call. The spatial nature of the SVE allowed the students to control the levels of privacy (intimate vs. public) and expansiveness (wide open vs. small and restrictive). Some students engaged in side-conversations during the class, and one student expressed the value of being able to do this in a situation when there was no in-person interaction with each other.

> **S10** I had a few casual conversations in the Hubs spaces with other students… This helped me get to know some of my classmates more, especially since our other in-class meetings were in the Teams video call interface which was more of a lecture style. Being able to chat with other students in the Hubs spaces was similar to taking breaks in a real physical classroom and getting to chat with classmates. I think this was especially important this year with almost all classes being in a video call lecture style because of Covid.

Students also experienced objects and space at scale, getting a more "hands-on" feeling than when using a video calling solution. This was particularly true when using a VR headset. This allowed them to get a better idea of scale, texture, and color. This was especially important if the student wanted to 3D print a model they created, as assigned to one of the classes for an assignment.

Students reported feeling engaged and connected in class as a result of the spatialized environment. We observed non-conversational collaboration (e.g. drawing in space), speaking one-on-one, greeting, joking, dancing and casual conversation in small groups between formal class periods.

> **P3** Many students said that they appreciate how social this class was: I build in social time into the class but the ability to meet in Hubs was what really did it here. A couple students said the class never felt like they were doing work and yet when they looked back they realized they did a ton and learned a lot!

4.4.3 Sense of place. The immersive classroom space seemed to provide a "sense of place" where people could gather, especially notable during a pandemic lockdowns. These became places to visit that allowed participants to safely socialize during a time when people were limited on travel. Professor reported that students seemed more communicative and social in VR than on video calls. We observed that this in turn fostered feelings of community, intimacy and safety similar to what might exist in a physical classroom environment. Visual, audio, spatial emotional cues Lighting became very intentionally designed by some of the participants towards the end of the semester with many participants choosing 'sunset' and soft lighting. Sound also became an important emotive tool, with people choosing soundscapes such as water rippling, bird chirping, and ambient music.

4.5 Communities

Spending a majority of the class time over the semester in a spatial SVE, we saw the emergence of communities in the different classrooms. We can look at social engagement and communities at three different levels. At the lowest level, we have interaction between individuals through avatars. Next, we have the social behavior of the group of users as a whole within a particular space or virtual room (social behavior). At the highest level, we have different ways in which various student rooms were connected that enabled the groups to explore the larger universe (neighborhoods). We expand upon each of these levels in the following subsections.

4.5.1 Avatars. Avatars represent the users of an SVE, and play an important role in defining the social aspects of the experience. Mozilla Hubs allows its users to choose an avatar before joining a room. The user can select from an avatar gallery, or create a custom avatar and upload it to the Hubs servers for use as an avatar. However, few DIY avatars were used by students or professors. Most participants used pre-made avatars from the Hubs avatar library. However, one professor (P4) created a custom avatar in his own likeness for the final class presentation at the end of the semester where other students and professors could also join (akin to a gallery show). Several students used avatars as a form of playful self-expression, often times reflecting a theme or a current event (eg. Halloween themed avatars). Some students chose avatars that matched the theme of the worlds they created, for instance a ghost in a graveyard or a toucan in a jungle. Some students chose huge avatars out of step with the environments scale, and others chose an avatar that played off their names. .

In addition to visual representation of the avatars, avatar head and body movement also provided non-verbal social cues. The student could control the avatar behavior to different levels depending on whether they were using a VR headset or a computer screen. The avatar's gaze in the virtual world reflected where the user was looking within the SVE, either using a VR headset or through the computer screen using a keyboard and mouse. Additionally, when using a VR headset (in particular a headset with two 6-DOF controllers like the Oculus Quest), the avatar's hands were visible and controllable–they mapped directly to the position of the controllers in physical space. This was not possible when the students joined using a computer, and some feeling of co-presence was lost (however we did not quantify or measure this). Hand motion was a strong non-verbal indicator of engagement for headset users. In the absence of both motion and audio (for instance if the student left the computer to get something else, or if there was a connection issue), an avatar still indicated some presence. However a continued absence of motion and audio made others wonder if the user was still present. The virtual representation in the SVE was not always congruent with the ground truth in the physical reality, and caused confusion sometimes. This was one of the reasons for various groups to keep using other channels of communication like video calling or text messages in the background, to help troubleshoot when there was no response.

Fig. 8. The students usually huddled around the professor when a topic was being discussed. However, even in this configuration, we can see different levels of proximity to the professor, from an intimate, close ring, to a slightly looser ring, to completely disjointed meandering.

4.5.2 Social Behaviors. Avatar movement allowed students to organize themselves in a variety of configurations depending on the context and the situation. These behaviors were reminiscent of social behaviors one might find in a physical setting in various context. Some of the arrangements we saw were: students in a circle around the professor (similar to in a physical open classroom arrangement during a lecture) (Figure 8), divided into smaller groups for side conversations (typically after the "main" event or lecture has ended), following a leader (typically when somebody was giving the others a tour of their space), and wandering around outside the main crowd giving themselves space to meander. These factors might be important for learning in classrooms, in particular for a discipline like art and design, as reflected by Professor 1 (P1):

> **P1** Zoom is either on or off, but in Hubs you can be on but still wander off somewhere, . . . be out in the periphery (which is nice for people who want to step away from the spotlight). Hubs lets people draw and otherwise make stuff while listening: I think people might learn better if they can doodle or somehow participate in the lesson.

Fig. 9. Three neighborhood topologies emerged that connected the student rooms and aided navigation in different ways.

4.5.3 Neighborhoods. For each of the art and design classrooms we observed, part of the work over the semester involved authoring content that could be shown in the SVE. Since it was important to manage the ownership and authorship of specific content within Hubs, all classes decided that each student should author their own Mozilla Hubs room. The Seed Space that we provided to the professors at the beginning of the semester was used as a meeting space. However, we repeatedly observed that navigating between separate student-created Hubs rooms was confusing for the classes at the beginning, leaving some students lost and unsure how to find the rest of the class. Over time, the different classrooms developed various strategies to connect the various student-created rooms together to aid in navigating these spaces. These strategies were created in response to several needs that arose over the duration of the semester. For instance, it was important to enable efficient transitions between student spaces during class time, when the focus was on critique of the student space by the students. Some sessions like the final show-and-tell for one of the classes was open to the public, and the expected attendance could have been more than 50 users. For this session in particular, the classes needed to manage performance limitations (number of people and objects in a space).

We saw the emergence of three neighborhood topologies (Figure 9):

- Centralized: With the Seed Space acting as the central node, student rooms were linked bidirectionally from the classroom using portals. In this scenario, typically the class would start in the Seed Space, then navigate to the first student's room, then navigate back to the seed space, and so on.
- Ring: With the seed space acting as a starting/ending node the student rooms were linked in a one directional ring using portals. In this scenario, typically the class would start in the seed space, then visit the first student's room. This would link to the next student's room, and so on until all the rooms had been visited and everybody was back in the seed space.

- Disconnected/time mapped: Each room was listed in a spreadsheet with assigned entry/exit times. The student rooms were not interlinked, but some linked back to the seed space. This was the least structured, but the most efficient way of navigation, and was used frequently through the semester for everyday class sessions. However, this required some familiarity with how the Hubs software system worked and how to navigate using links.

The classes shifted from one form of neighborhood navigation to another over the course of the semester. For instance, most classes used a variation of the "Disconnected / time mapped" navigational technique for most of the semester. However, instead of maintaining a spreadsheet with links and entry/exit times, the students would share the link to their room in an external communication application like Zoom, and the professor would set a time limit for everybody to critique that student's work.

While the various topologies enabled the classes to be run and navigate between student rooms in certain ways, the way that the audience was asked to navigate also encouraged the formation of different kinds of communities and groups within the audience. For instance, in one of the class sessions for the group that employed the centralized neighborhood topology, the professor and students were free to navigate the spaces as they wished. There was no structure to which participant visited which connected student room in which order, and the navigation was completely unstructured. The connected nature of the centralized topology enabled the participants to explore freely without feeling lost. However, at the end, all the participants had their own thoughts on the experiences, and there was no shared understanding since this was inherently a solo experience. The same group used a different, more structured, navigation strategy for the final presentation day where they were expecting more than 50 people in the audience. When a user joined the central seed space room, they were assigned one of three groups: A, B, or C. Similarly, the student rooms were also categorized into one of these groups. All users in group A visited the rooms categorized under group A, and the same happened for B and C respectively. This encouraged the formation of mini cohorts within the larger group, where the cohorts discussed what they saw and explored, and developed a shared understanding. At the end of the session, these groups met again in the central node, and switched to a video call in order to share their thoughts and discuss what they experienced.

5 DESIGN IMPLICATIONS

. Note: Our guidelines are for the *short term*, not long term. i.e. they're for practical implementation of an SVE today. Many of these guidelines relate to technical limitations that exist today but might not exist any more in a couple of years. These issues are not with the medium of an SVE inherently, but with the current technological environment.

Immersive technologies remain less accessible to most classrooms today as compared to a laptop screen due to cost concerns [41]. While it might be feasible for institutions to acquire enough VR Head-Mounted Displays (HMDs) for instructors, it is impractical to expect all students to also have access to a VR headset at scale. Additionally, the barrier to entry for instructors to use VR content in the classroom is heightened by the level of technical expertise required in creating educational VR content, as well as managing the VR HMDs and aiding the students with troubleshooting in case of technical difficulties [48]. This indicates that **a laptop-centered design is a crucial first step for high customer adoption of spatial interfaces**.

Related to this, it will also be crucial to **design for asymmetric device access** in shared and collaborative spaces. Providing asymmetric access to immersive social learning environments through a multitude of devices can enable all students to access these spaces, while also allowing users with VR HMDs to take advantage of the higher immersion that the medium affords. We should aim to design spaces which support this behavior, and don't disadvantage one medium over another.

Next, we found that many classes switched between the SVE and video calls for several reasons, including lack of congruence between the user's representation in the physical world and the virtual world. When a user lost connection, for instance, it was hard to detect this only from the Hubs space. This suggests that some **representation of the user's state**, which might be their webcam video feed, might be important to incorporate in an SVE for adoption in education. Some SVEs like Gather.town and Spatial already do this.

In addition to the video information, it would also help to be able to **switch between spatial communication channels and uniform communication channels** (like in a video call). Our results suggest that a mixed VR/video call model with fluid transitions between spatial, few-to-few, and all-to-all audio options might be the best practice for usability.

Our results reveal the potential benefits of **integrating easy-to-use authoring tools** like Spoke for Mozilla Hubs to expand remote education and remote work audiences, in particular for art and design education. Additionally, the high usage of built-in libraries within Hubs and Spoke indicates that students were more focused on communicating an idea, rather than creating a high-fidelity scene. While this will not be the case for every class, we should keep in mind that sometimes simple and low fidelity is better than complex and high fidelity.

Finally, most frustrations for students and professors were caused by performance issues. This suggests that offering fast, stable hosting is crucial. Additionally, for scenarios where there might be a disconnect in the user's flow (for instance transitioning between spaces), **including fall back audio channel is crucial**. The classes we observed used an external tool like video calls to maintain this channel of communication.

6 DISCUSSION

The value of immersion. While we were initially surprised at the low rate of VR adoption, it doesn't seem very surprising in retrospect. There were several reasons that the users did not access the SVE from a VR HMD. However, most of these reasons were related to issues like usability, performance, and physiological responses. These are technological and physiological hurdles that will reduce over time with the inevitable development of better processing technology, wider adoption of VR to remove its novelty, and better optics. However, we observed other valid reasons for not using VR *by design*.

One of the trends we saw was that classes consistently used channels of communication outside of Mozilla Hubs. This usage served specific use cases and solved specific problems, like being able to hear others irrespective of where they were, or to help troubleshoot technical issues. This finding interacts with the idea of immersion in the literature. One of the most important aspects that researchers talk about when discussing virtual worlds and SVEs is immersion, usually along with presence. While we did not measure the system's level of immersion or the participants' level of presence, switching to other channels of communication is potentially immersion-breaking. However, the classes we studied continued using others channels of communication since these features had specific functions and solved a specific problem–accomplishing the goal for which the users were meeting was more important than maintaining a high level of immersion in the SVE.

Additionally, one class mentioned that they did not see the value in accessing Hubs from VR–that they were getting all they could to their advantage from using it on a 2D screen on a laptop. This suggests that even in a perfect world without performance limitations, where everybody was well-acquainted with VR, and nobody fatigued from its use, the 2D screen experience would still be the better choice for this class. While VR as a medium has been shown to be effective for learning and collaboration , Mozilla Hubs did not have the tools that a student in a design class might require to do assignments, brainstorm, or to create projects. Hence, the main draw for Mozilla Hubs for these classes was its social aspect, rather than the creative aspect. As we've seen in our spatial pedagogy, communities, and neighborhoods results in the previous section, the primary contribution of Mozilla Hubs was what it enabled through its spatial nature rather than the immersion of VR. While we did not test with any other SVE, we surmise that other SVEs like gather.town which don't provide an option to switch to VR would also likely provide much of the same social benefits that we saw with the use of Mozilla Hubs. This draws attention to the importance of considering the use cases that the applications we design will be used for, and to evaluate whether those use cases might require immersion.

From social to collaborative. The above findings indicate that that immersion is not the most important aspect of SVEs and VR–when looking at a complex, real-world example over time, we found that there is more to the collaborative aspect of doing work together than feeling present with each other in a social space. These opportunities need to be leveraged in order to make SVEs truly collaborative, rather than a social meeting place. For instance, exploring tools within the SVE that enable users to accomplish specific tasks like brainstorming or idea generation amongst others. Currently, the primary purpose of SVEs like Mozilla Hubs is to enable people to meet together in a spatial environment, not to accomplish specific tasks together. It is no surprise, then, that the users did not use VR devices to access the spaces–they felt that the advantage of using a tool like Hubs was its spatial nature (which could be accessed from a desktop), not the immersive nature of VR.

7 OPEN QUESTIONS AND FUTURE WORK

One of the important findings from this study was the use of multiple devices in the experience of the shared virtual environment for a classroom. This leads us to wonder how might laptops, immersive HMDs, and smart phones be integrated into a seamless tool ecosystem, which play well together, utilize each other's strengths while mitigating their weaknesses.

User representation in SVEs is a multifaceted challenge. Users' facial expressions and body language was lost through avatar use in Mozilla Hubs. How might users be represented in the virtual space that maintains some level of congruence between their phsyical and virtual selves? Could virtual avatars function as both camera replacement in video calls and as spatial social bodies in SVEs? What level of realism is required for these virtual avatars in an SVE? Past research has shown that mutual behaviour, emotion, and

One reason that some users preferred using laptop rather than a VR headset was the ability to multi-task on a laptop while in the SVE. This is because of the relative ease of context-switching that one can do on a laptop (switching browser windows can lead you from Mozilla Hubs to your email inbox). This is not possible in a VR headset since the user is immersed in the environment and cannot switch out as easily as on a laptop. How might SVEs in general and remote collaboration tools in particular take advantage of the focus offered by headsets and the multitasking offered by laptops?

8 CONCLUSION

The COVID-19 global pandemic took the world by surprise when our everyday interactions were taken online. Remote work and remote learning seem to be an extremely plausible future in the current circumstances. Our study of four design classrooms using a Shared Virtual Environment as part of the class curriculum sheds light on the strengths and weaknesses of SVEs as pedagogical tools in design education. We observed several themes in the way the classes used the SVE, including a trend in device usage (students preferred laptops over VR), communication channels (students and professors utilized multiple parallel channels of communication in addition to VR), ease of use of creative tools (students preferred simple low-fidelity creation tools over complex high-fidelity creation tools), and the emergence of a spatial pedagogy and communities. We also discussed the design implications for these findings, and discussed the value of immersion and argued for a move from *social* SVEs to *collaborative* SVEs. As we move forward to an era of potentially ubiquitous use of immersive media like VR and MR, we are hopeful that the findings from this paper would help researchers design SVEs that enable their user to accomplish collaborative tasks in concert with each other.

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