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Evaluation and Comparison of Desktop Viewing and Headset Viewing of Remote Lectures in VR with Mozilla Hubs

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Abstract

We study student experiences for VR-based remote lectures using a social VR platform, evaluating both desktop and headset-based viewing in a real-world setting. Student ratings varied widely. Headset viewing produced higher presence overall. Strong negative correlations between headset simulator sickness and ratings of co-presence, overall experience, and some other factors suggest that comfortable users experienced additional benefits of headset VR, but other users did not. In contrast, correlations were not strong for desktop viewing, and it appears to be a good alternative in case of headset problems. We can predict that future headsets will bring benefits to more students, as visual stability and comfort are improving. Most students report preferring a mix of headset and desktop viewing. We additionally report student opinions comparing VR to other class technologies, identifying difficulties and distractions, evaluating avatar features and factors of avatar movement, and identifying positive and negative aspects of the VR approaches. This provides a foundation for future development of VR-based remote instruction.

CCS Concepts
• ***Human-centered computing*** → *Virtual reality;*

1. Introduction

We study student experiences of a remote class delivered with a social VR platform. The study considered a natural "real-world" setting in that students were at home, using various consumer devices, and the study did not change course content or delivery method (which resulted from a VR class using remote instruction during the spread of SARS-CoV-2). Students attended class in both VR headsets and on desktop monitors. Lecture content was presented by a teacher using a VR headset and tracked controllers.

Remote classes have other motivations such as those related to reducing travel: reduced carbon use [Out20], saved time, and removing geographic constraints. Remote classes may reduce social stress, for example, from not having to be seen physically. Classes delivered with video tools such as Zoom or Skype may lack some interactivity or quality of in-person lectures. Networked VR offers an alternative with potential benefits from increased presence and social interactions. Educational VR may be best-suited to environments that emphasize spatial learning. But, it is less-commonly studied for lecture-style classes. Although there is substantial prior work considering VR for education, there is minimal published work on students attending class using headset VR in homes.

Our preliminary results showed a good median headset experience and some user sickness [YB20]. Other researchers reported higher social presence with similar headset VR than with Zoom video for a group meeting [SMLW20]. Headsets can be cumbersome and require specialized equipment, so it is important to understand benefits and trade-offs. Simulator sickness is a well-known concern for headsets, and it is important to determine its significance for home use in education. Desktop viewing is widely accessible and easy to deploy, but it may not provide the level of social presence that we consider a motivating factor for VR-based classes.

Students in our study rated factors such as presence, social presence, usability, and sickness. Additional questionnaire topics investigated communication methods, avatar features, Hubs features, etc. Results suggest that social VR platforms can be effective for remote lectures, with the exception of simulator sickness and technical difficulties. Even though some students experienced substantial simulator sickness, headset viewing provided increased presence overall. Even students with negative headset experiences reported high expectations for VR as a remote class platform for the future. Considering high correlations between reported sickness and other ratings in the headset condition, results suggest that future VR technologies with reduced simulator sickness would give additional advantages of headset viewing over desktop viewing. In the meantime, desktop viewing is a good alternative for those students who experience sickness or technical problems with headsets.

2. Related Work

VR for education has been suggested to increase presence, motivation, and engagement [MOM19] [BLW18] [MTM19] [PM18]

Figure 1: *A Lecture in Mozilla Hubs*

[AAW11] [Pso13]. For effective remote learning, factors like technical difficulties, distractions, and viewing-related discomfort need to be understood. Studies of technologies like video conferencing show that although they may be good for remote learning, technical problems or distractions are common drawbacks [ESKL11] [GC07] [Fre98] [JB01]. Campbell et al. found headset VR improved presence, closeness, and arousal, for business meetings, when compared to video-based meetings [CHC*19]. They also reported that female participants preferred VR avatars to real-life imagery. Borst et al. showed a benefit of incorporating live guidance by a teacher into networked VR for virtual field trips by small classes [BLW18], finding high ratings of presence, social presence, and other factors. Simulator sickness was not found substantial, but external distractions were found problematic when present.

Mozilla Hubs is a “social VR platform” on the Web and supports many devices (hubs.mozilla.com). Outlaw et al. used it for an ACM UIST 2019 virtual poster session. They observed an increased sense of presence and stated that "the participants felt involved ... as if they were watching the talks in the conference hall” [Out20].

Earlier examples of delivering remote content with VR include a 2011 study of an IBM meeting in Second Life, an online 3D world with avatars, typically viewed on a desktop monitor [ESKL11]. The virtual event was described as "fairly successful" except for technical problems. Second life was also used for a program committee meeting of IEEE VR 2009 [LRS09]. Results suggested that not many users had technical difficulties, even with little experience. Users did not prefer Second Life to a face-to-face meeting, likely due to the lack of presence of desktop VR.

Neither desktop nor headset VR has consistently been found better in VR work comparing viewing approaches. Some studies found that desktop VR outperforms headset VR in learning [SRV*19] [MTM19], navigation [SDP*09], or memory-based scenarios [RT18]. This may be due to increased cognitive load for headset VR [RT18] [MTM19]. Murcia-Lopez and Steed found that headset VR outperformed desktop for spatial learning in a high-fidelity environment [MLS16]. Another study favored headset VR for cognition [PBB*16].

3. Methods

3.1. Overview

Our study was conducted during 7 weeks of a remote class that met entirely in Hubs. The main independent variable was the viewing method used by students (headset or desktop VR), in a within-subjects study design with counterbalanced order.

3.2. Class Environment with Mozilla Hubs

We used Hubs because it is "lightweight" and usable on many devices. Hubs features are rudimentary but support key aspects of remote VR classes. Features used include: upload/download of lecture slides and videos, per-user selectable avatars with tracked head and hands, livestream video of the teacher, viewing capabilities like maximizing content with a button, walk/fly/teleport navigation, voice/text chat, and emojis emitted from avatars.

Figure 1 shows a Hubs lecture with a mix of students using desktop VR and headset VR. The image shows a lecture screen (uploaded PDF content) near its center, uploaded video objects to the right of the screen, a teacher avatar near the bottom right of the screen, a live-streamed webcam view of the teacher to the left of the screen, and student avatars in the virtual room. Some students are floating (fly-mode) for a better view.

The teacher used a Vive Cosmos headset to present in VR. Lectures introduced VR devices, their relation to human senses, and interface topics. Students occasionally presented their own content related to their semester projects, which were either game-type projects or independent studies with implementation.

Depending on a viewing condition, each student attended with a headset or on their desktop. Various headsets were used: five Oculus Quests (four standalone and one PC-driven via Oculus Link), four Oculus Rift CV1s, one Oculus Rift S, one Windows Mixed Reality HP headset, one Windows Mixed Reality Odyssey+ headset, and one HTC Vive. All of these devices have 6-degree-of-freedom tracking and 2 hand controllers. We believe 6-dof head tracking is essential for a good experience, because 3-dof devices suffer from a visual-proprioceptive mismatch that contributes to motion sickness. Monitor sizes for desktop viewing ranged from 13 to 42 inches, with a median of 17.5 inches.

3.3. Participants

The study includes 13 students: 11 undergraduates and 2 graduate students. All students were pursuing computer science degrees. Although these students are not representative of the general population, they are in a relevant demographic group for the early adoption of emerging technology and due to the growth of this major at universities. Most students had limited prior VR experience and the study shows a range of resulting experiences.

6 of the 13 students never used virtual reality before the class, with 4 others having used VR more than 20 times and the remaining 3 having used VR a median of "3 to 5" times. Only 3 students had ever used VR chat rooms outside of class. None had used VR to watch formal presentations.

11 of 13 of students had prior experience with video tools like

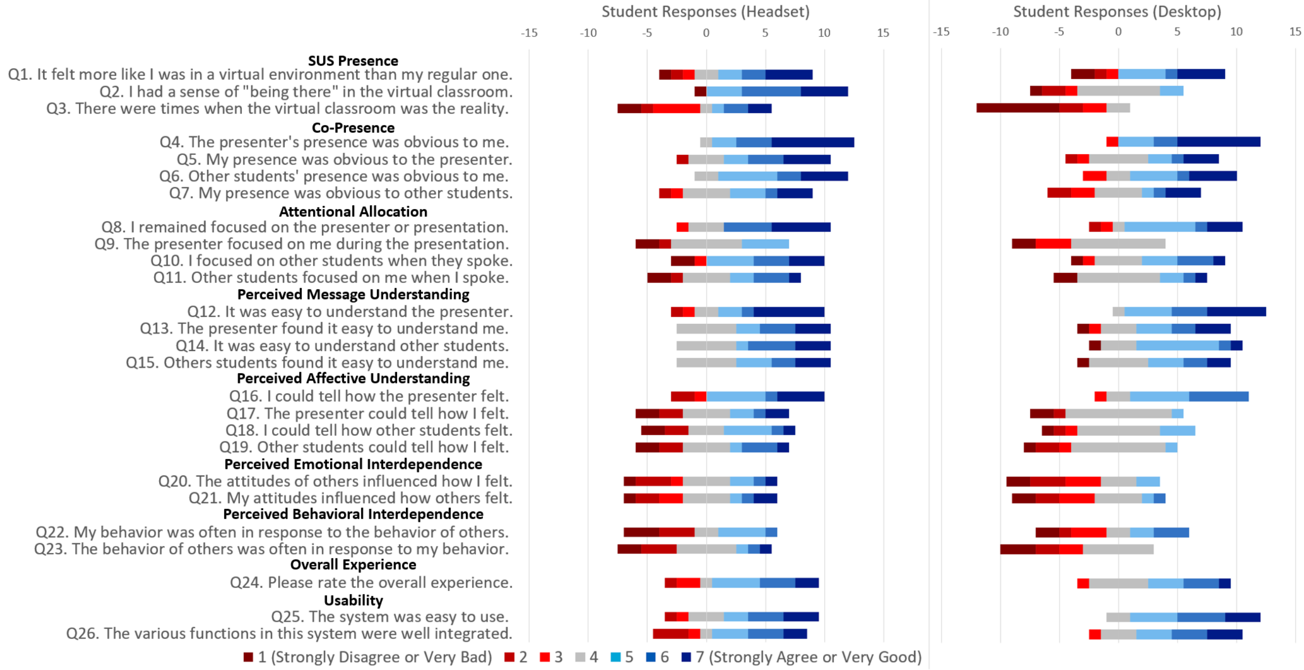

Figure 2: *Diverging Stacked Bar Charts, Counting Responses to Main Questionnaire Items (Headset and Desktop VR)*

Skype, Zoom, or Twitch. 10 had prior experience using these tools to watch a formal presentation.

Students' other classes used non-VR remote delivery in parallel with the VR class. 9 students took at least one live video class with a teacher and students seeing each other (multi-way live video), 6 students took at least one live video class with only teacher-to-student video (one-way live video), 8 students took at least one pre-recorded video class, and 9 students took at least one other type of class including: other uploaded content only (3 responses) and project classes with no lecture content (1 response).

3.4. Procedure

On selected days, students answered questionnaires (via forms linked from Hubs) with 7-point ratings, 4-point ratings, multiple choice, and short answer items.

3.4.1. Background Questionnaire

All students answered a background questionnaire once in the second week of remote lectures.

3.4.2. Desktop and Headset Viewing Questionnaires

Viewing questionnaires were given during the last 15 minutes of a class attended either in headset or on desktop. 5 of the 13 students rated headset viewing first (in the second week) and desktop viewing later (fifth week). The other students experienced conditions in reversed order in those weeks. We note that the unequal split did not favor headset viewing in results: 4 of 5 students who reported high sickness with headsets are in the later group and tended to give low headset ratings then (Section 4.2).

Viewing questionnaires asked students to rate experiences from one day each. Several questions were based on: immersive tendencies (ITQ) [WS98], SUS-Presence [SUS94], Networked Minds Social Presence [HB04], and simulator sickness (SSQ) [KLBL93].

3.4.3. Final Questionnaire

A final questionnaire was given on the last day of class (week 7). For this questionnaire, students were asked to reflect on their overall experience of the 7 weeks.

4. Results

	Headset		Desktop		Wilcoxon Tests	
Averaged Subscales	**Mean**	**Median**	**Mean**	**Median**	**Z**	**p**
Overall Experience	4.92	5	4.85	5	-.072	.943
SUS Presence	4.85	5	3.38	3.67	-2.103	.035 *
Co-Presence	5.52	5.75	5.13	4.75	-.746	.455
Attentional Allocation	4.63	5	4.27	4.5	-1.123	.261
Message Understanding	5.35	5.75	5.08	4.75	-.315	.753
Affective Understanding	4.25	4.25	3.94	4.25	-.420	.674
Emotional Interdependence	3.88	4	3.12	3	-1.249	.212
Behavioral Interdependence	3.42	4	3.31	3.5	-.223	.824
Usability	4.85	5	5.46	5.5	-1.025	.306

Table 1: *Subscale scores (using averages of contributing questions from Fig. 2) and statistical comparison of desktop to headset with Wilcoxon Signed Rank tests.*

4.1. Viewing Questionnaire: Experience Ratings

Fig. 2 summarizes response distributions for main items from viewing questionnaires. Table 1 shows mean and median subscale scores, where a student's subscale score is computed as the average of contributing items in Fig 2. The table also shows statistical comparison between desktop and headset subscale scores.

4.1.1. Overall Experience

Measuring overall experience allows us to gauge the general impression that students have of the VR lectures. We found that the overall experience (Q24) of desktop and headset was positive and similarly rated, with means of 4.92 and 4.85, and no statistically detected difference (Table 1).

A later section (Section 4.2) suggests a substantial effect of simulator sickness on this result and on some others.

4.1.2. SUS Presence

Presence in a (virtual) classroom is arguably the most notable feature that VR can add to remote lectures.

As expected, students experienced a higher sense of presence in headset viewing than desktop viewing in VR, with a statistically significant difference shown in Table 1.

4.1.3. Co-Presence

Co-presence is the "degree to which the observer believes he/she is not alone and secluded, their level of peripheral or focal awareness of the other, and their sense of the degree to which the other is peripherally or focally aware of them" [HB04]. We believe co-presence is important in classes by promoting more engagement with the teacher and students. Students will likely not be prompted to interact with others if they are not aware of others' presence or if they don't think others are aware of them. Students may not feel like they belong to a university class if they do not experience co-presence. With many universities recently switching to remote classes, this sense of belonging could be vital.

Both desktop and headset VR were positively rated for co-presence (Table 1), without a statistically detected difference. Students overall felt a sense of co-presence in both experiences.

For headset VR, both questions about others' presence being obvious to the viewer (Q4 and Q6) did not receive any negative responses, with mostly positive responses (Fig. 2).

Negative co-presence responses may indicate that a few students feel isolated. It appears that even when students feel others are present, a few of them do not expect that others see them as present. Q5 and Q7 had more negative and neutral responses than Q4 and Q6 for both headset and desktop viewing.

4.1.4. Attentional Allocation

Attentional allocation "addresses the amount of attention the user allocates to and receives from an interactant" [HB04]. It lets us know if students are able to focus on others when they speak, and if they think others focus on them.

On average, there was not much difference between attentional allocation in headset and desktop VR. While headset and desktop subscale scores were not statistically different, we see from Fig. 2 that Q9 received no positive ratings for desktop viewing, with headset viewing receiving 4 positive ratings. Presenter focus may be unclear in a desktop view.

4.1.5. Perceived Message Understanding

Perceived message understanding tells us if students understand the teacher and if they think the teacher understands them.

Subscale scores for headset and desktop VR appear similar (mean of 5.35 and 5.08, respectively).

One possibly interesting aspect is that only headset viewing received negative responses for Q12, while only desktop viewing received negative responses for the other items (Q13-Q15). For headset viewing, we were surprised that this pattern differed from Co-Presence and Attentional Allocation patterns. Considering the question style, answers may reflect audio quality in Hubs. Most of the speaking was by the presenter, and there were more student-reported audio glitches with headset viewing (Section 4.3.3).

4.1.6. Perceived Affective Understanding

Affective understanding is "the user's ability to understand an interactant's emotional and attitudinal states as well as their perception of the interactant's ability to understand emotional states and attitudinal states" [HB04]. It is important, for example, to know if the audience understands a presenter's attitude (e.g., if the presenter is more serious about a topic, students may focus more).

Table 1 suggests similar mean ratings and the same median rating for headset and desktop VR for perceived affective understanding. Fig. 2 suggests that the response shapes may be different for the two viewing methods: Desktop responses tended to be neutral, while headset responses were more dispersed, including more negative and positive responses. This suggests a more consistent or less notable experience on desktop than in headset.

Some affective cues may be missing due to limitations of avatars. More positive ratings in Q16 than for Q17-Q19 could reflect that the teacher's voice was the only one heard often.

4.1.7. Perceived Emotional Interdependence

Emotional interdependence is "the extent to which the user's emotional and attitudinal state affects and is affected by the emotional and attitudinal states of the interactant" [HB04]. Engagement between students and a teacher is important for education.

Ratings of emotional interdependence are moderate overall, without a statistically significant difference between conditions (Table 1). Students do not report affecting each other's attitudes much. However, in headset viewing, a few students give very high ratings, suggesting possible notable exceptions. Desktop VR is more consistently negative. It seems at least some students sense interdependence more in headset than in desktop viewing.

4.1.8. Perceived Behavioral Interdependence

Behavioral interdependence is "the extent to which a user's behavior affects and is affected by the interactant's behavior" [HB04].

We see similar results between perceived behavioral interdependence and perceived emotional interdependence for headset viewing. For desktop viewing, no student felt they affected the behavior of others (Q23 has no positive desktop response). We consider other evidence for interdependence in Section 4.4.6.

4.1.9. Usability

For deployment to a wide range of students, it is important for remote instruction tools to be easy to learn and use. We see positive usability ratings for both headset and desktop viewing (mean 4.85 and 5.46). Low ratings in the headset condition appear associated with sickness (Section 4.2).

4.2. Viewing Questionnaire: Simulator Sickness

Simulator sickness is an important consideration for VR. In extreme cases, it makes VR unusable. Moderate cases may substantially degrade the experience. Unlike lab settings, a home setting for VR does not allow consistent control over devices and conditions, leading to additional concern about sickness.

Viewing questionnaires asked students to rate the extent to which they experienced a subset of symptoms from the SSQ [KLBL93]. For each student and condition, we computed a sickness score as the average of their responses to five 4-point sickness questions.

4.2.1. Headset Viewing Sickness

Fig. 3 shows the symptom distributions for headset viewing. 9 of 13 students reported at least slight "general discomfort". Other symptoms that were reported high at least twice were fatigue and eye strain. Two students gave maximum ratings (rating 4): One for fatigue, headache, and difficulty focusing or concentrating; and the other for general discomfort. Students encountering sickness were able to switch to desktop viewing. 3 students reported removing headsets for varying amounts of time during the lecture due to discomfort or sickness symptoms, reported as head pain or nausea.

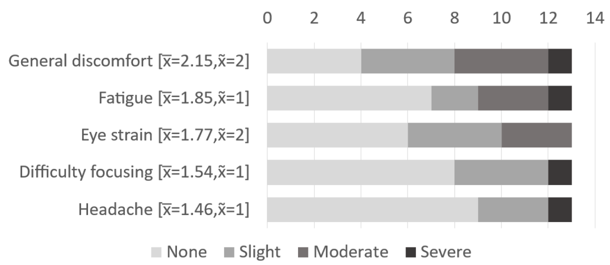

Figure 3: *Sickness symptoms for headset viewing*

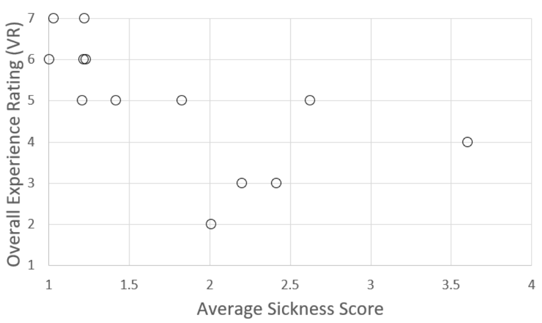

Figure 4: *Overall Rating (Q24) vs. Sickness Score (Headset)*

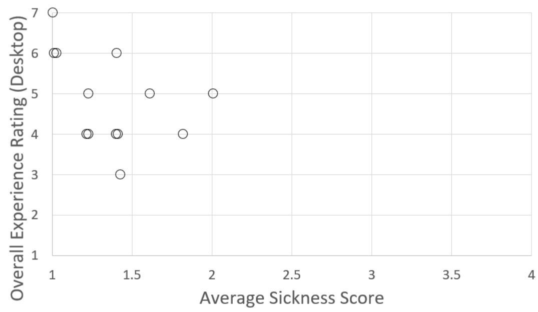

Figure 5: *Overall Rating (Q24) vs. Sickness Score (Desktop)*

Figure 4 shows that as sickness score increases, the rating of overall experience decreases (Q24). Notably, all users with sickness score below 2 gave positive overall experience ratings, but only one user with a score of at least 2 gave a positive overall rating.

Statistically, very strong negative correlations were found between sickness score and usability (Spearman r_s=-.830, p=.000) and between sickness and perceived message understanding (r_s=-.801, p=.001). We found strong negative correlations between sickness and overall experience (r_s=-.792, p=.001), SUS presence (r_s=-.719, p=.006) and co-presence (r_s=-.623, p=.023).

Some question groups did not correlate much with sickness, suggesting students were not just answering all questions the same way. For example, we did not find notable correlation between sickness and "prospects" ratings (Section 4.3.1) about expectations of VR being good for education (r_s=.055,p=.859). This could indicate that students believe their current experience is not indicative of the future of VR, so we additionally checked for correlation between overall experience and the prospects rating, with no detected correlation (r_s=.233,p=.444). Other items that were less correlated with sickness include attentional allocation (r_s=-.472,p=.103) and perceived behavioral interdependence (r_s=-.474,p=.101).

Two subscales had moderate correlation results, nearly strong, but with slightly weaker correlation coefficient or borderline non-significant p: perceived affective understanding (r_s=-.593,p=.033), perceived emotional interdependence (r_s=-.520,p=.069).

We did not find significant correlation between sickness and prior experience level with headset VR (r_s=-.194,p=.525) or with a score summing two questions about general mental and physical wellness on the lecture day (r_s=-.501,p=.081). Some readers may find the latter "near significant", weakly suggesting a relationship.

Sickness did not appear tied to any particular device type. The average sickness scores of at least 2 occurred with Oculus Rift CV1 (3 of 4 such devices) and Oculus Quest (2 of 5).

Based on these correlations and additional inspection, comfortable users tended to give higher scores to headset viewing. Several items received no negative headset ratings from the 8 low-sickness students: Q2, Co-Presence (Q4, Q5, Q6, Q7), Q8, Overall experience (Q24), and Usability (Q25, Q26). Considering that reducing sickness is a major area of VR research and development, we predict more users will be comfortable in future systems, likely leading to higher ratings of headset viewing over desktop.

4.2.2. Desktop Viewing Sickness

For desktop VR (Fig. 5), the highest sickness score was 2, reported by one student, who reported a combination of moderate headaches and slight fatigue, eye strain, and difficulty focusing or concentrating. Here, sickness was not strongly correlated with overall experience rating (r_s=-.452,p=.121). Due to the less notable result than for headset viewing, we do not further detail desktop sickness.

4.3. Viewing Questionnaires: Additional Insight

4.3.1. Comparison to In-person and Videoconference Classes

Table 2 summarizes student responses when asked to list the main advantage and disadvantage of headset and desktop classes compared to in-person and video-conferencing classes.

For positive aspects of both VR approaches compared to in-person classes, students value the ability to stay at home, level of engagement/interactiveness, and some aspects of content viewing. Positive aspects compared to videoconferencing are mainly related to level of engagement/interactiveness, not having to be seen or use a webcam, and avatar presence. The negative aspects for both VR approaches when compared to both in-person and video-conferencing classes are mostly technical difficulties. Not many students specifically listed sickness, although it correlated negatively with rating questions.

We also asked if students expected VR to be a good replacement for in-person and video-conferencing classes within 10 years, using a 7-point rating. Headset viewers responded with means of 5.15 (vs. in-person) and 5.85 (vs. video). Desktop viewers responded with means of rating of 4.54 and 6.46.

4.3.2. Feature Helpfulness

The Viewing questionnaires asked students to rate the helpfulness of 12 features.

For headset viewing, the top 5 most helpful features (by mean response) were: a pointer used by the presenter (the presenter used a Hubs marker tool that emits a ray), the presenter's avatar, live (real-time) communication, embedded videos, and the presentation slide display. These results show that students value presentation features the most. The 3 least helpful features, by mean, were the student's hand gestures, other students' hand gestures, and the live video stream of the instructor. Features with intermediate ratings were: the student's avatar, the presenter's hand gestures, the chat feature, and having room-like surroundings.

For desktop viewing, the top 5 most helpful features were the same as for headset viewing, with different ordering by means. They were (by mean response): the embedded videos, the presentation slide display, live (real-time) communication, the presenter's avatar, and a pointer used by the presenter. The 3 least helpful features, by mean, were the student's avatar, other students' hand gestures, and the student's hand gestures. Features with intermediate ratings were: having room-like surroundings, the live video stream of the instructor, the chat feature, and the presenter's hand gestures.

4.3.3. Technical Problems/Distractions

The viewing questionnaires had students report the extent to which they experienced certain distractions or problems. Technical problems asked about were: audio glitches, video glitches, problems with a display device, and problems with an input device. Distractions asked about include: noise in the real environment around the student, shifting attention to other activities in the surrounding environment, distractions from other objects or features in the virtual room, distractions from people's avatars, shifting attention to other activities on the computer, and electronic alerts such as: phone, email, messages.

For headset VR, the technical problems reported most often were audio (11 of 13) and video glitches (8 of 13). Other technical problems such as display/input device problems were minimally reported. The most highly reported distraction was noise in the real environment around the student (7 of 13 students experienced this on some level, with levels ranging from 2-4). Other distractions were minimally reported. In addition to distractions listed in our question, students reported: checking the time with external tools like SteamVR, choppy audio, and switching between Hubs rooms.

Desktop VR had fewer technical problems compared to headsets. The main reported technical problem was audio glitches (9 of 13), with all other technical problems being minimally reported. The most reported distraction was noise in the real environment around the student (7 of 13 students). Other distractions were experienced on some level by less than half of the class.

One notable observation about reported distractions is that more students "shifted attention to other activities on the computer" for desktop viewing (6 of 13) than headset viewing (2 of 13). But, students in headset experienced more distractions from objects or features in the virtual room than desktop viewers (5 and 2 out of 13, respectively). These results mirror the fact that desktop viewers can easily access other other activities on the computer, while headset viewers only have objects in the virtual world readily accessible.

Technical problems with a display/input device and video glitches appear more prominent in headset viewing.

4.4. Final Questionnaire Results

The final questionnaire gives additional insights. It had students reflect on the entire 7 weeks of remote classes. Statistical hypothesis tests were not performed for final questionnaire items.

4.4.1. Final Impression

Students were asked for an overall rating of desktop and headset VR as a medium for remote classes. Responses were positive and similar for desktop and headset viewing (mean of 5 and 4.77).

We then asked students how often they experienced a glitch that substantially degraded the experience. Headset scores suggested more glitches than desktop (mean of 3.54 and 2.92).

Knowing glitches and sickness can degrade overall experience, we then asked: if all glitches were fixed, how would they rate headset/desktop VR as a medium for classes overall. Mean ratings appeared higher than for the first experience question, with headset

	Positives	Negatives
Desktop vs. In-Person	Ability to stay home (4), ease of attending (3), access to higher quality materials (1), ability to focus on content (1), increased confidence speaking up (1), less stressful (1), embedded videos (1)	Technical difficulties (6), distraction (2), obtrusive avatars (1), other students loud (1)
Headset vs. In-Person	More engaging/interactive (4), ability to stay home (2), ease of use (2), embedded videos (1), better view (1), increased confidence speaking up (1), ability to review content (1)	Technical difficulties (7), VR fatigue (1), isolation (1), distraction (1), seeing own avatar (1)
Desktop vs. Videoconferencing	More engaging/interactive (5), presence of avatars (3), not having to be seen/no webcam (2), access to class materials in Hubs (1)	Technical difficulties (3), distractions (2), harder to see (1), load times (1)
Headset vs. Videoconferencing	Not having to be seen/no webcam (3), more engaging/interactive (3), less distraction (2), ability to see slides like regular classes (1), ability to gesture (1), sense of being there (1), ease of use (1)	Technical difficulties (5), discomfort from headset (2), distraction (1), load times (1), VR fatigue (1)

Table 2: *Positives and Negatives of Desktop and Headset Classes Compared to Video-Conferencing and In-Person Classes, with Number of Related Responses in Parenthesis*

ratings showing possibly more change (headset mean changed from 4.77 to 5.92, desktop from 5 to 5.62).

4.4.2. Sense of Belonging to a University

As mentioned in Section 4.1.3, sense of belonging to a University during remote instruction might be related to experiences such as co-presence. Students were asked to rate their sense of belonging to a university class for several class styles (Fig. 6). VR in headset was rated best of the remote methods (mean 3.23) but not as high as in-person classes. Desktop VR received intermediate ratings (mean 2.62). Real in-person classes received all "very high" ratings, as would be expected.

The results suggest that headset VR is promising for maintaining a sense of belonging during remote classes. Desktop VR appears somewhat less promising. It received 1 more "very high" rating than multi-way video, but its mean rating is lower. We believe that low ratings of pre-recorded video reflect the importance of "live" delivery, and mostly low ratings of one-way video reflect the importance of two-way social presence.

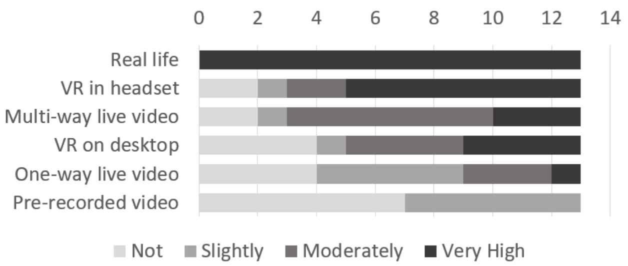

Figure 6: *Students' sense of belonging to a University class*

4.4.3. Desirable Missing Features

We asked students to list additional features they would like that were missing from Hubs.

For headset viewing, suggested features included: a way to signal a question/raise hand feature (2 responses), better ways to view media (1 response), a more classroom-like setting (1 response), better overall system design (1 response), easier mute toggle (1 response), note taking capabilities (1 response), a way to read the chat logs (1 response), better video support (1 response), and clearer instructions for controls (1 response).

Here we see some basic useful features are missing from Hubs like taking notes and persistent chat logs.

Desktop suggestions included: a way to signal questions/raise hand (3 responses), a better way to feel immersed (1 response), a more classroom setting (1 response), ability to hide others' avatars (1 response), better overall system design (1 response), simple controls (1 response), more communication methods (1 response).

We see from the responses (headset and desktop viewing) that several comments suggest improving communication methods.

4.4.4. Communication Methods

Communication is a key aspect of classes. Besides speech, there are subtle things that contribute to communication, such as hand or head motions.

Students were asked: not considering any technical glitches, how helpful they considered various methods for a student to communicate to others during a VR class (4-point ratings from Not to Very Helpful). Communication methods listed by the question included: voice chat, pointing with hand/pen/ray, text chat, hand motion (e.g., raise hand), triggering an icon or emoji, moving whole avatar nearer, and nodding/bobbing your avatar head.

All communication methods received a high mean rating (mean of 3 or higher). Voice chat was unanimously rated as "Very Helpful" (mean 4). The second and third highest rated methods were pointing with hand/pen/ray and text chat (mean 3.69 and 3.54). Other listed methods had a mean of 3.

These results show that multiple factors contribute to effectively communicating with others. Some of these features are only achievable through attendance methods like headset VR.

4.4.5. Avatar Features

Avatars are important for social presence in VR, and they may aid understanding. Recall that students value the presenter's avatar from results in section 4.3.2.

The final questionnaire asked students how effective various features of the teacher avatar were. The features asked about were: having a visible body, head pulse that indicates speaking, avatar/head aim to face you or other objects, natural (tracked) head motions, hand motion or gestures, and eye movement/blink.

Each of these features received a mean rating of 3 or higher (using 4-point ratings from Not to Very Effective), with the exception of eye movement/blink (mean 1.62). This was a surprising exception, as we expected an automatic Hubs eye movement/blink to make the avatar seem more "alive". The two highest-rated features on average were having a visible body and a head pulse that indicates speaking (mean of 3.38 for both).

Students were asked what additional features would improve the teacher avatar's effectiveness. Responses included: more in-depth tracking (1 response), making the teacher more visible (1 response), live video feed (1 response), having a live body model (1 response), a way to see when someone raises their hands (1 response), a laser pointer (1 response), and mouth animations (1 response).

When asked what features would improve student avatars, responses mentioned: a better way to signal questions (2 responses), more in-depth tracking (1 response), removal of fly mode because it is distracting (1 response), better teleportation (1 response), making body invisible to self (1 response), better audio controls (1 response), a laser pointer (1 response), and having pictures of each student as their avatar (1 response).

Overall, a main suggestion based on these responses is an extended teacher avatar (full body tracking, mouth movements). Consistent with Section 4.4.3, some students want a more reliable way to get the teacher's attention for questions.

4.4.6. Factors of Avatar Movement

We asked students how often they move their avatar when someone enters their personal space and how much they position their avatar to avoid invading someone else's personal space. The mean responses for headset viewing (7 point ratings from Never to Very Often) were 5.46 (to avoid others) and 5.31 (to avoid invading). The mean responses for desktop were 4.62 and 4.77. This could suggest more behavioral interdependence in headset VR than in desktop VR – students may be more aware of, or more responsive to, personal space in headset VR.

When asked what other things made students move their avatars, responses for headset VR included: to get a better view of lecture content (7 responses like this), to hear better (6 responses), and accidental movement (2 responses). Desktop responses included: to get a better view of lecture content (10 responses), to hear better (5 responses), and someone blocking vision (1 response).

From this, we see that a main reason for people to move their avatar is for better visuals or audio. Visual factors may include limited resolution of headsets/monitors and other avatars occluding sight. Audio changes are related to Hubs' spatial audio, which lowers audio levels with distance. VR lectures could be enhanced with software that better optimizes audio levels and that renders occluding avatars in a see-through or minimized manner.

4.4.7. Viewing Preference : Desktop or Headset

In the final questionnaire, we asked students how they would prefer to attend a remote VR class (desktop, headset, or some mix) if all glitches were fixed. Results were that 5 of 13 students would like an even mix, 4 students prefer mostly headset, 2 students prefer mostly desktop, with the remaining two students split between headset-only and desktop-only. So, we see that a majority of students prefer to attend either an even mix of headset and desktop viewing or mostly headset viewing.

5. Discussion and Conclusion

We studied student experiences using both VR headsets and desktop monitors. Results suggest that social VR provides a promising alternative to other remote presentation approaches, with the main exception of simulator sickness for some cases.

Presence was significantly higher with headsets than desktop viewing. In several ratings, headset and desktop VR did not differ statistically overall, but this reflects that headset ratings varied in strong correlation with simulator sickness symptoms encountered by several students. Considering all results together suggests additional benefits of headsets for comfortable students.

Technical difficulties and distraction are common obstacles for remote class technologies ([ESKL11] [GC07] [Fre98] [JB01]). Distractions with desktop and headset VR differ due to different accessibility of internal vs. external objects (Section 4.3.3). Audio and video glitches were reported for our class (Table 2; Section 4.3.3). This is likely related to the widely-varying home computing environments that result from the natural "real world" study settings (considering better results from more controlled setups, e.g., [BLW18]). Understanding real-world use is important for assessing remote educational technology. Pre-training and system tuning may reduce problems. Meyer et al. found that pre-training "had a positive effect on knowledge, transfer, and self efficacy" [MOM19].

Some students noted that they value having avatars and not being seen on video (Sections 4.3.1 and 4.3.2). This recalls Campbell's study wherein female participants preferred VR avatars to video in meetings, possibly due to social pressures [CHC*19].

Students rated the teacher's avatar as very important (Section 4.3.2). Some students would like to see a more detailed teacher avatar with features like full body tracking and mouth movements (Section 4.4.5). We also see that some students want to more easily get the teacher's attention. Communication and presentation features are essential overall (Sections 4.3.2, 4.4.3, and 4.4.4). Elsewhere, we summarize teacher suggestions about how the tools could improve [YB20].

Most students reported that they prefer to attend a VR-based remote class using a mix of headset and desktop viewing (Section 4.4.7). This provides good motivation to further explore these methods for attending remote classes and to study their tradeoffs with respect to different class topics and activities.

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