UsherXR: Placing Remote Students in Their Classroom Seats as 2D Video Sprites

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Abstract: This paper introduces *UsherXR*, an extended reality (XR) system that integrates both remote and local students into the same seat with little to no latency. The instructor wears an XR headset running in passthrough mode that renders remote students as live video sprites virtually placed into the empty seats of the classroom. *UsherXR* achieves scalability with the number of students by integrating the individual remote student video feeds into a video atlas on an edge server, which is then sent to the headset of the instructor. *UsherXR* was evaluated with good results in a controlled IRB-approved user study that investigated the effectiveness of *UsherXR* from the remote and local student perspectives.

1 INTRODUCTION

Distance education has the potential to revolutionize learning. Providing students with the ability to participate in educational activities remotely will allow them unprecedented scheduling flexibility. Currently, the most common method of conducting synchronous remote learning is through video conferencing (e.g., Zoom). Remote students are captured by their computer's webcam and the video feeds are then displayed on instructor computer. However this method has many shortcomings. In particular, the instructor must maintain awareness of the local classroom while they are teaching and so it can be difficult for instructors to interact with remote students at the same time.



Figure 1: UsherXR system perspective. **Above:** a view of the classroom from local student perspective. **Below:** view of classroom from instructor perspective (instructor XR headset frame).

In this paper we investigate the use of XR to improve the connection between remote students and the instructor. We introduce *UsherXR*, an end to end system for synchronous remote lecture attendance. *UsherXR* is illustrated in Fig. 1. The instructor wears an XR headset that overlays a virtual classroom onto an existing classroom and teaches in a local classroom as usual (as can be seen in Fig. 1 above image). The headset is in passthrough mode, so the instructor sees the local classroom and the local students (e.g., 1), as well as the remote students rendered as virtual billboards aligned with the empty seats of the classroom (e.g., 2). The below image in Fig. 1 is an actual frame from the instructor XR headset. Within Fig. 1, remote students appear as if they are physically within the classroom and can interact with the instructor the same way local students do.

One major issue with achieving remote student communication is scalability as the XR headset has very limited processing power and cannot process the bandwidth required for multiple video feeds. *UsherXR* provides scalability with the number of remote students by integrating the video feeds of individual

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remote students into a video atlas on an edge server, e.g., the instructor or classroom computer. The video atlas is then sent to the instructor headset where it is partitioned into individual video textures rendered throughout the local classroom. This shields the headset from the overhead of having to receive and process multiple video feeds. Instead the headset only needs to parse through a single video feed.

We have conducted an IRB-approved, controlled, within-subjects user study (N = 28) from the perspective of both local and remote students in which we compared *UsherXR* to conventional video conferencing (i.e., Zoom). In the experiment, (N_1 = 16) participants served as local students and another (N_2 = 12) served as remote students in a classroom where and instructor gave the same mock-lecture on solving quadratic equations. The study results show that *UsherXR* succeeds at connecting students and instructors across disparate locations, allowing for seamless communication between all parties. As expected, local students objected to the instructor wearing the bulky XR headset, pleading for the adoption of emerging headsets with a minimalist form factor.

2 PRIOR WORK

We first discuss prior work in the area of constructing a hybrid classroom that contains both local and remote students (Sec. 2.1), and we conclude with a discussion of the use of extended reality in constructing hybrid classrooms (Sec. 2.2).

2.1 Hybrid Local+Remote Classrooms

Synchronous hybrid classrooms allow local and remote students to engage in learning together in real time while enabling instructors to interact with both groups simultaneously (Hastie et al., 2010).

A recent systematic literature review explores the current state of hybrid classrooms, highlighting their advantages, challenges, and offering practical guidelines (Perraton, 2020; Raes et al., 2020; King et al., 2001; Fidalgo et al., 2023). The review identifies several pedagogical and organizational benefits of hybrid classrooms, including increased student recruitment, more flexible learning environments, reduced instructor workloads, greater inclusion of external educators, and improved opportunities for underrepresented student groups (Wiles and Ball, 2013; Carmel Parker White and Plonowski, 2010). However, the review also points to numerous challenges, particularly for instructors who must balance maintaining consistent instructional quality for both local and remote learners (Brady and Pradhan, 2020; Lin and Gao, 2020; Powell et al., 2022; Dantes et al., 2022; Godara et al., 2024; Peper et al., 2021).

With the rise of videoconferencing, remote participation in lectures has become more common. Participants' webcam feeds are displayed on a grid, enabling everyone to see one another. While this method is cost-effective, it often fails to foster meaningful connections between participants, especially in larger groups. Consequently, remote learners frequently experience feelings of isolation, largely because distance learning struggles to recreate the immersive and interactive environment of a physical classroom (Davis et al., 2021; Luiz Antonio Joia, 2021). This sense of isolation is particularly pronounced for students who lack intrinsic motivation or proactive engagement with their learning goals (Sherry, 1995). Researchers have long identified limited opportunities for interaction as the primary cause of this isolation (Childs et al., 2024).

One earlier hybrid classroom model used videoconferencing software to deliver lectures to remote students while simultaneously conducting in-person lectures for local attendees (Triyason et al., 2020). This setup incorporated video feeds of remote participants, displayed on screens positioned within the classroom, enabling the instructor to see remote students while addressing the entire class. However, this approach came with high equipment and logistical costs due to the need for customized audio, visual, and camera systems that aligned with the capabilities of cloud-based platforms.

Our work aims to prioritize remote student participation while keeping the instructor physically present in the classroom. Our design extends the local classroom to accommodate remote learners by integrating their presence into the instructor's field of view through virtualized displays, optimizing instructor awareness while minimizing the cost and complexity.

2.2 XR Hybrid Classrooms

Although extensive research exists on distance learning and the application of extended reality (XR) in education, there is limited focus on using XR technologies to effectively integrate remote learners into physical classrooms.

An early exploration proposed the concept of a Shared Reality Environment (Cooperstock et al., 2001), where video feeds of remote participants were projected into the local classroom space. This initial implementation suggested that incorporating such video streams could enhance the feeling of copresence for all participants. One of the earliest prac-

tical applications of this concept involved extending the classroom by projecting virtual rows of seats onto the back wall, creating a virtual extension populated with background-subtracted video sprites representing remote students (Nita-Rotaru et al., 2007). This design placed remote learners within the instructor's visual field, leading to improved instructor awareness of their presence. However, while this method required only modest equipment—an additional ceiling-mounted projector and a screen—its limitation was that remote participants were relegated to virtual rows behind the in-person students, even when closer, vacant seats were available. This positioning reduced the instructor's ability to maintain consistent awareness of remote learners.

An XR hybrid classroom system dubbed *HyperXRC* (Huang and Popescu, 2024) took a similar approach to *UsherXR*, integrating remote students into the perspective view of an instructor wearing an XR headset. Like *UsherXR*, *HyperXRC* allows the instructor to see local students as normal without obstruction as well as students who participate remotely that rendered in the headset. The study showed that the use of an XR headset helped the instructor maintain awareness of the remote students significantly better than when using videoconferencing while preserving the instructors ability to maintain awareness of local students. However, the *HyperXRC* implementation uses simulated remote students, modeled with prerecorded videos downloaded onto the headset. Therefore, the study was limited to the instructor and local student perspectives, and did not investigate the remote student perspective. In contrast, our *UsherXR* system supports live remote students, and our study reports on the remote student perspective. Furthermore, *HyperXRC* does not allow the remote students to see the local students, breaking down an important communication channel that is needed to make the remote students parts of the local classroom. On the other hand, our system *UsherXR* does provide remote students with a view of the local classroom.

3 SYSTEM DESIGN

We designed a extended reality classroom which is capable of integrating both local and remote students into a single classroom session. We first describe the key requirements of this extended reality classroom (Sec. 3.1) then give an outline of our design/implementation (Sec. 3.2).

3.1 Key Requirements

In designing our extended reality classroom, we needed to meet several key requirements

Remote student acquisition. We are primarily concerned with the scenario whereby multiple remote students connect to a single classroom from disparate locations. In order for these students to attend the class remotely, they must first be acquired using a device. Additionally, we are concerned with the ability of remote students to be conveniently acquired utilizing relatively common devices such as the webcam of a personal laptop. We also sought to integrate background subtraction into our program in order to provide a real-time video sprite which can be transmitted into the local classroom while minimizing the difference between local and remote students.

Remote student display/communication with local instructor. The remote students must be added into the classroom seamlessly with the local students. Crucially, they must be integrated in such a way that it will not negatively impact the local students and the instructor will not need to significantly change how they teach the class to interact with the remote students. Notably, conventional video conference applications such as Zoom do not meet these requirements as the instructor must repeatedly look back and forth between the device used to run the application and the local students in order to address both, Managing remote students in this manner reduces the ability of the instructor to monitor both local and remote students.

By utilizing the XR headset's video passthrough mode to create a virtual classroom to overlay the classroom over an existing classroom, with the seats being manually assigned by the instructor, we are able to integrate both local and remote students into the field of view of the instructor. This allows the instructors to monitor both without the need to switch back and forth between the local students and another device thus fulfilling the requirements.

Seamless communication between remote students and the instructor. For remote students to be able to communicate with the instructor, there must be no delay between their image being captured and what the instructor sees. This presents a significant challenge as modern XR headsets have very limited processing power and thus sending a large number of video feeds into a headset will result in significant latency in the video feeds. Our solution to this is to collate all the video feeds into a single video atlas on a separate device then stream the video atlas to the headset. The headset can then break the video atlas apart as needed and spread the individual video feeds across the room into the empty seats as 2D video sprites.

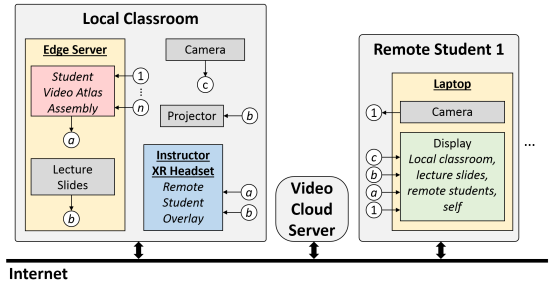


Figure 2: Overview of *UsherXR* design.

3.2 Implementation

To address the requirements described above, we have designed *UsherXR* with the architecture depicted in Fig. 2. In order to enable seamless communication between all parties and to acquire remote students, *UsherXR* utilizes a Video Cloud Server to transmit data between all components in our system. Each remote student has access to their own personal laptop on which a program will be downloaded. The program will consist of a camera the will acquire each student through their webcam then send the acquired camera feed (1...n) to the Video Cloud Server, and a display that will show a series of video feeds. Next, another program running on the edge server in the local classroom will retrieve each of the camera feeds from the Video Cloud Server then assemble the feeds into a single video atlas (a). Additionally, the lecture slides are also held on the edge server and will streamed out via the internet as another video feed (b). The atlas and the lecture slides are then sent back to the the Video Cloud Server. Both the atlas and the slides are shared with each remote student through the display incorporated into the program running on their computer.

Meanwhile, the XR headset displays the slides to the instructor using a virtual banner hanging from the ceiling over the classroom. A program running on the XR headset also breaks apart the video atlas so that individual camera feeds are divided then placed onto billboards located in empty seats across the room as shown in Fig. 3. The instructor is then able to see and interact with local and remote students at the same time. Also within the local classroom are a camera that captures a video feed of the room (c) and sends it to the Video Cloud Server and a projector that will retrieve a video feed of the lecture slides and project it to the local students.

The goal of *UsherXR* is for the instructor to maintain awareness of both remote and local students while largely eliminating latency from the remote student feeds to ensure timely communication between the remote students and the instructor.

Our *UsherXR* implementation uses Unity 3D version 2022.3 and a Meta Quest 3 headset with frame rate 72Hz. For our video cloud server we utilize Agora, a open source platform that enables video calling and live streaming to various apps and websites. The rendering load is negligible, as the system only has to render a few sprites.

4 USER STUDY

We have evaluated *UsherXR* in a user study approved by our IRB. Our study compares *UsherXR* to videoconferencing from the perspective of both local and remote students.

4.1 Methods

Participants. We evaluated the *UsherXR* design from the remote and local students point of view with (N_1 = 16) participants serving as local students and another (N_2 = 12) served as remote students, recruited from the student population of Purdue University West Lafayette Campus. 47% of participants were between the ages of 18 to 22, 50% were between the ages of 23 and 29, while only 3% were older than 30. 73% of participants identified as male while 23% identified as female, and 4% preferred not to answer the gender question. Many participants expressed familiarity with video conferencing software such as Zoom with 10% answering that they use such software daily, 60% stating that they use similar software at least once a week, and only 30% reporting that they use video conferencing only once a month or less. Most participants also had taken courses using distance education. Only 3% of students stated that they have never taken a course remotely when compared to 17% who had taken one course remotely and 80% who had taken multiple courses remotely. In regards to AR and VR experience, 27% of participants owned a VR or AR headset while 73% did not. 13% of participants had used a VR headset at least once, 63% had used a VR

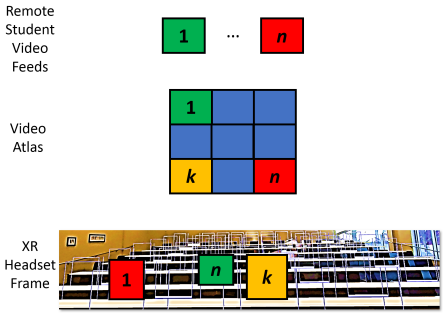


Figure 3: Diagram of video atlas broken apart into individual video feeds.

headset a few times and 23% had used a VR headset frequently. 23% had never used an AR headset, 13% had only used an AR headset once, 47% had used an AR headset a few times and 17% had used an AR headset frequently.

Task. Participants are asked to watch an instructor's presentation on quadratic equations, after which they answered a questionnaire on the presentation they had watched. During the lecture the instructor occasionally called upon either the whole class or individual students to answer questions and how well the students are able to respond is measured using timers by experimenters.

Conditions. We used a within-subject, controlled study design. In a first, control condition (CC), the instructor used a laptop to see the video sprites of the remote students as well as the lecture slides using the videoconferencing application Zoom. In the experimental condition (EC), the instructor wore the XR headset that instructor wore the XR headset that provided the *UsherXR* visualization.

Experimental Procedure. The experiment was held in a lecture room with three sessions total. In the first session there were 5 local student participants and 5 remote student participants. In the second session there were 7 local students and 3 remote students. In the third session there were 4 local students and 4 remote students. Each consenting participant was first asked to fill out a demographics questionnaire as well as a consent form. Once both forms had been filled out, they all attended a ten minute lecture on quadratic equations. Each student participant was remunerated with a $25 gift card.

Data Collection. In our user study we collected data using a variety of objective and subjective metrics. During each of the sessions in both control and experimental conditions we asked two randomly selected local students questions (Loc Q1: "Can you explain to me what a quadratic equation is?" Loc Q2: "Can you explain to me how to find the solution when there is only a single solution to the quadratic equation?") as well as two remote students questions (Rem Q1: "Can you explain when does a second order equation have a single distinct real solution?" Rem Q2: "While there are no real solutions in the situation where the discriminant is negative we will still have solutions. Can you explain to me if discriminant is negative what kind of solution will we have?"). Experiment proctors recorded the speed with which the students were able to respond using timers.

After the lecture was completed, we asked the participants to answer a series of questionnaires. One questionnaire is the NASA Task Load Index which consists of six scale scored on a scale of 1 to 10 with 1 being the lowest score and 10 being the highest score that measures total workload. Another questionnaire is the System Usability Scale which consists of 10 questions scored on a five-point Likert scale which is used to evaluate the usability of the system from the student's perspective. The final questionnaire is a subjective experience questionnaire scored on a five-point Likert scale to collect the student's opinion on whether they preferred the lecture given using *UsherXR* or the traditional video conferencing software.

There were two sets of questions, one for local students and one for remote students. The questions for local students were: LQ1: "It was easy to follow the instructions given by the instructor"; LQ2: "The instructor seemed to look at the ceiling all the time"; LQ3: "The instructor seemed to look at their laptop all the time"; LQ4: "It was hard to pay attention to the instructor"; LQ5: "I felt like the instructor could not see me"; LQ6: "It was frustrating to not hear the remote students"; LQ7: "I did not like that the instructor wore a headset that was hiding most of their face"; LQ8: "I wouldn't mind attending a class taught this way". The questions for remote students were: RQ1: "It was easy to follow the instructions given by the instructor"; RQ2: "The instructor seemed to look at the ceiling all the time"; RQ3: "The instructor seemed to look at their laptop all the time"; RQ4: "It was hard to pay attention to the instructor"; RQ5: "I felt like the instructor could not see me"; RQ6: "It was frustrating to not see the local students."; RQ7: "I liked that I could see the other remote students"; RQ8: "I liked that I could see my own video"; RQ9: "I did not like that the instructor wore a headset that was hiding most of their face"; RQ10: "I wouldn't mind attending a class taught this way".

Data Analysis. To analyze the answers to the questionnaires, we give each question a numerical score. The numerical score of negative questions are flipped, for more to always mean better. For the NASA Task Load Index a lower score is meant to signify a better result while for the System Usability Scale and student subjective experience questionnaire a higher score means a better result in our analysis. Our study utilizes a within-subjects design with two conditions (Experimental and Control) and thus we generate two sets of data. Descriptive statistics are presented numerically with tables and graphically with box-plots. Inferential statistics of our non-normally distributed data relies on the Wilcoxon Signed-Rank non-parametric test, with a statistical significance threshold of 0.05.

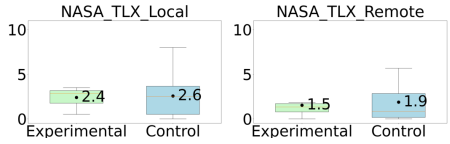


Figure 4: NASA TLX scores for local and remote students.

4.2 Results

Objective Metrics. Experiment proctors recorded the time it took for both local and remote students to respond to questions from the instructor which can be seen in Table 1. In both *Control* and *Experimental* conditions students were able to respond to the instructor near instantaneously.

NASA Task Load Index (TLX). A box plot showing the results of the NASA TLX survey for remote students can be seen in Fig 4 left image. The average NASA TLX score for remote students was 1.6 in the *Experimental Condition* and 2.0 in the *Control Condition*, difference without statistical significance.

Fig 5 shows the results of sub-scales of individual areas of workload. Table 2 contains a summary of the averages of the scores of the remote students for NASA TLX. Among all the sub-scales observed, it was only Frustration where there was a statistically significant difference between *Control* and *Experimental*, with *Experimental* obtaining better results (1.25 vs. 2.67). A summary of the results of the Wilcoxon Signed-Rank Test performed on the data from the remote student NASA TLX scores can be seen in Table 2.

Fig 4 right gives a box plot of the NASA TLX survey results for local students. The average NASA TLX score for local students in the *Experimental Condition* was 2.4. Meanwhile, the *Control Condition* obtained a 2.6 score for local students. No statistically significant difference was found.

Fig 6 gives results of the sub-scales of individual areas of workload. A summary of the averages of the scores of the local students for NASA TLX can be seen in Table 3. Among all the sub-scales observed, it was only Temporal where there was a statistically significant difference between *Control* and *Experimental*, with *Experimental* obtaining better results (2.27 vs. 3.13). A summary of the results of the Wilcoxon Signed-Rank Test performed on the data from the remote student NASA TLX scores can be seen in Table 3. Among all the sub-scales observed, all had a p-value above 0.05 indicating that there was no statistically significant difference between conditions.

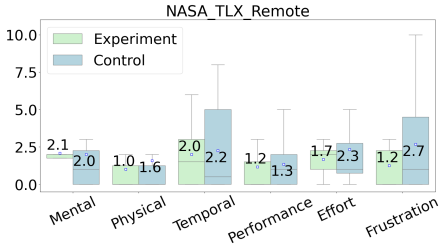


Figure 5: NASA TLX sub-scale scores for remote students.

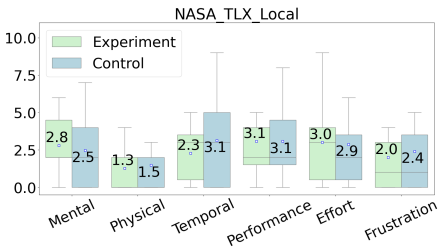


Figure 6: NASA TLX scores of individual sub-scales for local students.

System Usability Scale, SUS. The average SUS score for remote and local students in the *Experimental Condition* can be seen in Fig 7 with an average of 60.2 for remote students and 61.2 for local students. The average SUS score for remote and local students in *Control Condition* can also be seen in Fig 7 with Remote = 75.6 and Local = 68.3. These results map between the "Good" and "OK" adjectives on the SUS scale and are not significant statistically significant.

Subjective Experience Questionnaire. A summary of the results of the Wilcoxon Signed-Rank Test performed on the data from the remote student subjective questionnaires can be seen in Table 4. Among all the sub-scales observed, only RQ4 had a p-value below the threshold 0.05 with the experiment condition receiving a higher rating than the control condition indicating that there was a slight preference from remote students to the experimental condition when compared to the control condition. This preference can likely be attributed to a greater responsiveness on the part of the instructor due to UsherXR.

A summary of the results of the Wilcoxon Signed-Rank Test performed on the data from the remote student subjective questionnaires can be seen in Table 5. Among all the sub-scales observed, LQ2, LQ3, LQ5, LQ7 , LQ8 had p-values below the 0.05 threshold. These answers indicate that in both *Control* and *Experimental* conditions the local students expressed frustration with the setup. In the *Control* session local students expressed issues with how frequently the instructor needed to look at their laptop. In the

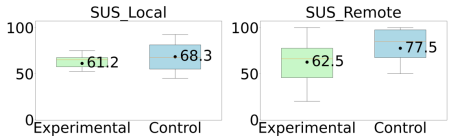


Figure 7: Average SUS scores for local and remote students.

Table 1: Objective metric results. Note that a 0 means that the student was able to respond in less than on second.

Row Labels	Session 1				Session 2				Session 3			
	Rem Q1	Loc Q1	Rem Q2	Loc Q2	Rem Q1	Loc Q1	Rem Q2	Loc Q2	Rem Q1	Loc Q1	Rem Q2	Loc Q2
Experiment	0	0	0	0	0	0	0	0	0	0	0	0
Control	0	4	0	2	0	0	0	0	0	0	0	0

Table 2: Summary of average NASA TLX scores and Wilcoxon Signed-Rank Test Scores of individual sub-scales for remote students. CC refers to control condition, EC refers to experimental condition. χ refers to test Statistic and p refers to p value.

Sub-Scales	Conditions		Test Results	
	CC	EC	χ	p value
Mental	2.00	2.08	9.5	0.83
Physical	1.58	1.00	10.5	0.55
Temporal	2.25	2.00	21.5	0.91
Performance	1.33	1.17	15.0	0.67
Effort	2.33	1.67	17.5	0.55
Frustration	2.67	1.25	8.5	0.18

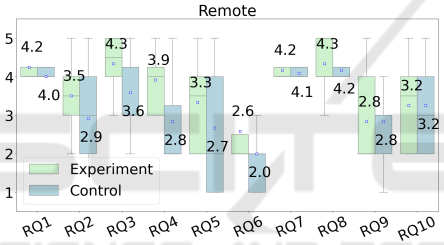


Figure 8: Five-point Likert scale subjective experience questionnaire answers for remote students.

Experimental condition the students expressed issue with how the instructor did not appear to be looking at them and that the instructor's face was obscured. Overall the students expressed a slight preference from the *Control* session and using Zoom.

Table 3: Summary of average NASA TLX scores and Wilcoxon Signed-Rank Test Scores of individual sub-scales for local students. CC refers to control condition, EC refers to experimental condition. χ refers to test Statistic and p refers to p value.

Sub-Scales	Conditions		Test Results	
	CC	EC	χ	p value
Mental	2.47	2.80	43.0	0.55
Physical	1.47	1.27	14.5	0.62
Temporal	3.13	2.27	40.0	0.43
Performance	3.07	3.07	38.5	0.97
Effort	2.87	3.00	42.0	0.81
Frustration	2.40	2.00	25.5	0.84

Table 4: Summary of Wilcoxon Signed-Rank Test Scores of the subjective questionnaires for remote students.

Questions	Test Results	
	Test Statistic: χ	p value
RQ1	5.0	0.48
RQ2	18.5	0.35
RQ3	14.0	0.16
RQ4	5.5	0.04
RQ5	6.0	0.17
RQ6	13.5	0.28
RQ7	9.0	0.74
RQ8	10.5	0.53
RQ9	22.0	0.95
RQ10	18.0	1.00

Table 5: Summary of Wilcoxon Signed-Rank Test Scores of the subjective questionnaires for local students.

Questions	Test Results	
	Test Statistic: χ	p value
LQ1	7.0	0.11
LQ2	3.0	0.01
LQ3	6.0	0.02
LQ4	13.5	0.13
LQ5	5.0	0.01
LQ6	16.0	0.12
LQ7	16.5	0.03
LQ8	13.5	0.04

5 CONCLUSIONS

We report on the design, implementation, and evaluation of an XR hybrid local+remote classroom that places remote students into the field of view of the instructor, at parity with local students. This way,

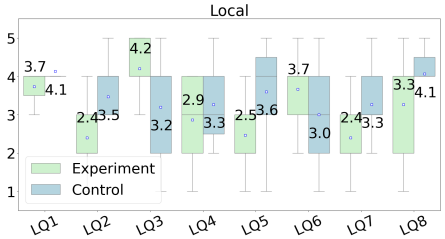


Figure 9: Five-point Likert scale subjective experience questionnaire answers for local students.

the instructor is able to monitor the body language of remote students and notice their desire to interject, without having to switching back and forth between looking at the local classroom and at their computer screen. Our system relies on commodity level components and infrastructure, including an all-in-one $500 XR headset for the instructor, a computer classroom serving as an edge server, and conventional campus WiFi connectivity, which are important prerequisites for mass deployment across campuses. Objective metrics from the user study show that *UsherXR* allows remote students to respond to prompts from the instructor nearly instantly. Our system aggregates the videos of remote students into a video atlas on a nearby edge server, shielding the headset from the complexity of having to handle individual remote student video streams. The current study investigated the local student and remote student perspective, complementing earlier studies such as that involving *HyperXRC* (Huang and Popescu, 2024), which used simulated (prerecorded) remote students.

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