Bridging the Distance in Education: Design and Implementation of a Synchronous, Browser-Based VR Remote Teaching Tool

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Abstract

The rapid shift to remote education has presented numerous challenges for educators and students alike. Virtual Reality (VR) has emerged as a promising solution, offering immersive and interactive learning experiences. We design and implement a synchronous, browser-based VR teaching tool. The tool is compatible with budget VR equipment and enables meaningful engagement between teachers and students in a virtual setting, as well as active participation and interaction across a range of platforms, thus solving a range of disadvantages of current approaches.

CCS Concepts

• ***Applied computing*** → ***Distance learning; Collaborative learning; Interactive learning environments;*** • ***Human-centered computing*** → ***Human computer interaction (HCI);***

1. Introduction

The growth of online education has led to the transformation of higher education globally. Already in 2011, 65% of institutions reported that online learning was critical to their long-term strategy. Today institutions are leveraging technology to improve the quality of education and reach a wider audience through remote teaching [Ken15].

The COVID-19 pandemic, further accelerated the shift towards remote learning, resulting in a significant transformation in education delivery and access. Over 1.1 billion school learners were affected by the pandemic at that time, with school closures impacting 117 countries [UNE22]. The transition from traditional classrooms to remote learning presented significant challenges, as educators and students had to adapt to unfamiliar platforms, new tools, and different pedagogical approaches. One of the most significant challenges that emerged was the lack of interaction, engagement and synchronous learning. The following problems of remote learning have been identified [Mor22]:

- Dull Instruction: Remote learning can lead to passive and monotonous instruction, particularly when students are required to sit passively and listen to videos and presentations.
- Lack of Social Interaction: The absence of social interaction in remote learning can have psychological consequences for students, leading to feelings of loneliness and isolation.
- Lack of Interaction and Synchronous Learning: Remote learning tools often offer limited opportunities for interaction and synchronous learning. Students turning off their cameras during video conferencing sessions, limited non-verbal cues, and reduced peer-to-peer interaction can hinder effective communication and engagement.

However, there are important benefits to remote learning which include overcoming geographic barriers, providing an inclusive learning environment for people with physical disabilities and long-term health conditions, and promoting affordability by removing expenses connected to traditional education like transportation, accommodation, tuition fees, and course materials.

Technologies like virtual reality (VR) or augmented reality (AR) provide immersive learning opportunities that raise student engagement and encourage participation. As technology continued to evolve, VR/AR found its way into various educational settings, including classrooms and virtual laboratories. It provides students with immersive experiences, enabling them to explore and interact with subjects that were otherwise challenging or impossible to access. From virtual field trips to historical reconstructions, VR opened up new possibilities for engagement and experiential learning. For example, students can view microscopic objects in 3D, or stand in the middle of a physics simulation. It was shown that students who used VR for learning three-dimensional vectors in an introductory physics university course outperformed those who did not, especially in tasks where visualization was important [CHZ22].

VR increases student participation and engagement, understanding and retention. A study comparing VR with traditional textbook-based learning and video watching showed that the 3D immersion

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and interactivity of VR may have a substantial impact on learning [AvM18]. Participants in the VR condition had increased retention and understanding when compared to the video condition.

Additionally, VR is credited with enhancing students' understanding and retention of complex concepts, such as mathematical concepts, which are represented in a 3D space, as well as skills transferable to real-world contexts. A review study [HMEW20] suggests that VR offers learning advantages, especially in scenarios that demanded intricate spatial comprehension and visualization. The majority of procedural tasks demonstrated an advantage of using immersive VR, indicating successful virtual skills acquisition transferable to real-world contexts. This capability of allowing repeated practice in a safe, resource-efficient environment might be one of VR's most intrinsic advantages. Anticipating technological advancements, increased creative content, and the ability for instructors to design custom immersive VR experiences, the future of VR as a teaching tool appears promising.

Advantages of remote teaching are significant [LB20] and include:

- Immersive Experiences: AR/VR technologies can fully immerse users in a virtual environment where they can interact with virtual objects and individuals in real-time, leading to hands-on learning that simulates real-world experiences or presents complex information in ways that would not otherwise be possible.
- Increased Engagement: AR/VR experiences can engage students in hands-on, gamified approaches to learning in a variety of subjects, which have been shown to support cognitive development and increase classroom engagement.
- Improved Learning Outcomes: Immersive experiences have been shown to reduce cognitive load and distance, encourage higher engagement, and improve memory recall for complex or abstract topics, such as STEM subjects that often rely on 2D representations of otherwise intangible concepts.
- Access to Experiences Limited by Cost or Distance: VR can offer virtual experiences that expand access to educational opportunities that would otherwise be limited by cost or physical distance [FHW20].

While VR in remote education offers numerous advantages, it is not without its challenges. The expensive nature of VR technology, including both hardware and software, prevents its widespread adoption. Another concern is accessibility, as not all students may have the required technology at home, resulting in potential inequalities in a remote learning setting. Additionally, the lack of available educational VR content, along with the complexity and expense of developing high-quality content, presents hurdles that need to be addressed in order to fully leverage VR for remote learning.

In this paper, we present a remote teaching tool which addresses these challenges. We employ a browser-based virtual reality to build and execute a synchronous teaching environment that brings teachers and students together in a shared virtual space, enabling real-time interaction and collaboration.

Created as a browser-based VR education tool, it is compatible with affordable VR equipment. Students will be able to access and use the tool using a number of devices, including their smartphones. By eliminating the need for specialized, expensive gear, we greatly expand the tool's accessibility, making it simpler for a wider range of students to benefit from VR's educational advantages.

2. Related Work

In recent years there has been a great deal of interest and research into the use of VR in education. By delivering immersive, interactive, and engaging learning possibilities, VR has the potential to revolutionize educational experiences. This is why the topic of VR in education has become the focus of numerous studies [LB20].

In their systematic review [TK23], Turan and Karabey analyse the utilization of immersive technologies in remote education, exploring their advantages, disadvantages, and general features based on studies conducted since 2002. The use of immersive technologies was found across various disciplines, with a particular emphasis on science and medical education, as these tools enable the simulation of complex, high-cost, and potentially hazardous scenarios. Unity was often used as the application platform due to its open-source nature and user-friendly interface. The studies largely looked at characteristics related to academic performance. These factors are closely related to academic achievement and are important in determining how well technology works in learning contexts. Most of the paper proposed that the use of immersive technologies in remote education increased academic performance and motivation. The analysis of the studies emphasizes the need for a more widely available and reasonably priced immersive education option.

One of the biggest challenges in remote learning that VR can potentially mitigate is the lack of non-verbal communication in synchronous online courses [CMS*23], which we address in this paper. The level of interactivity serves as a one the primary determinants of the potential educational outcomes of an application, offering a spectrum that ranges from passive consumption of information to fully immersive, interactive experiences:

- Passive experiences - where users simply observe a virtual environment.
- Fully interactive experiences - where users can manipulate objects, navigate through the environment, and affect the course of the experience.
- Cooperative learning experiences - multiple users interact with each other within the same virtual environment. This can be further divided into asynchronous collaboration and synchronous collaboration.

In the current landscape of VR applications in remote education, passive experiences, while being engaging, often lack the depth of interactivity that can significantly enhance learning outcomes. For instance, *The Body VR*[†] takes visitors on an educational tour of the human body, letting them pass through the bloodstream and learn about how our cells function. However, the experience is largely observational with limited user interaction. Similarly, *Google Earth*

† https://www.oculus.com/experiences/rift/967071646715932 last accessed 2024-01-22

VR [‡] has undertaken the ambitious task of bringing the world to the user. It provides a platform for exploration where users can virtually go to numerous geographic places across the world. The user's function is primarily passive, limited to navigating through and observing the scene, despite the fact that this offers a distinctive and immersive visual experience. Another significant VR option is provided by *TechRow* [§], which aims to maximize the potential of experience learning for students. However, user engagement in the virtual environment is still limited, just like the aforementioned applications. *Eduverse* [¶] provides schools with a secure "metaverse". It is web-based, but it does not allow interaction with virtual items. Students can share experiences in a collaborative setting, but their activities are mostly confined to gazing, which limits the possibility for a completely interactive learning experience. A similar platform is *FrameVR* [‖] which simplifies the process of building a 3D virtual classroom or even an entire campus, providing students with an interactive virtual learning environment.

An example in the field of fully interactive experiences is the simulator of traditional ink-writing *You, Calligrapher* [**]. Li et al. [LFJ22] examine the impact of VR education on learners and teachers in remote education, using *You, Calligrapher* as their experimental ground. Their findings reveal that VR technology can help establish an effective "face-to-face" teaching environment and address the challenges associated with supervision and providing teacher feedback, which are both commonly identified hurdles in remote education. *Prisms of Reality* [††] is another example of a fully interactive VR application for remote learning. Through immersive environments, this instructional tool aims to change the teaching of fundamental algebraic and geometrical ideas.

Typically, these interactive experiences support one-way interaction, that is, they give the user control over the environment, but they do not have a cooperative feature that would let a teacher and student work together on the same thing at the same time. This is a crucial function that our tool tries to offer. In light of this, we now shift our focus to explore the potential VR applications that facilitate cooperative learning, as this field is more closely aligned with the capabilities of our suggested solution.

Cooperative learning experiences in VR, may take on the form of asynchronous and synchronous collaboration. The first type refers to interactions that are not time-constrained; for instance, one student may interact with a virtual reality object and leave comments or revisions, which another student may access and respond to at a later time. Synchronous collaboration, on the other hand, enables several users to interact with the VR world and one another simultaneously in real-time.

‡ https://www.oculus.com/experiences/rift/1513995308673845 last accessed 2024-01-22

§ https://www.techrow.org last accessed 2024-03-15

¶ https://eduverse.com last accessed 2024-03-15

‖ https://learn.framevr.io last accessed 2024-01-22

** https://store.steampowered.com/app/1593700/You_Calligrapher last accessed 2024-03-15

†† https://www.prismsvr.com last accessed 2024-03-15

Google's *Tilt Brush* [‡‡], a powerful tool that enables painting in a 3D space, is an example of asynchronous cooperation in virtual environments. *Tilt Brush* offers an innovative palette to turn your space into a canvas and explore the limitless possibilities of creation. *MultiBrush* [§§] is a *Tilt Brush* add-on that enables multi-player interaction on the free and open source *Tilt Brush* code, enabling users to produce and appreciate art together.

Synchronous collaboration enables real-time interaction, fostering immediate engagement and meaningful connections among students and teachers. The ability for multiple users to remotely control the same object simultaneously amplifies the collaborative learning experience. However, despite its significance, the availability of applications that effectively facilitate synchronous collaboration remains limited.

Engage VR emerged as the only platform that effectively supports real-time interaction and collaboration among multiple users. It offers various features such as virtual events, corporate communications, education and training, media streaming, spatial recording, and content development tools. It facilitates multiple users interacting with the scene, fostering a collaborative environment.

We recognize the value of synchronous collaboration and addresses this gap by providing a platform where students and teachers can actively and synchronously interact with shared objects in virtual space. Using a browser-based approach as presented in this paper enables accessibility across various devices that support a web browser, including smart phones, tablets, and computers. Unlike *Engage VR*, our tool therefore eliminates the need for specific hardware or application installation, removing barriers that can hinder educational contexts. By leveraging the browser-based approach, we tackle the challenges of affordability and accessibility, making our tool accessible on various devices that support a web browser.

Additionally, our tool offers completely interactive cooperative learning experiences, going beyond passive and semi-interactive educational experiences. Our solution offers real-time collaboration, allowing students and teachers to interact with the same items and customize scenes, fostering a dynamic and engaging learning environment while many other programs on the market only offer limited interactivity.

Moreover, our tool stands out in terms of programmability, allowing the educators and learners to tailor the VR experience to their specific needs, incorporating complex animations, conditional logic, and other advanced features.

Mozilla Hubs [¶¶] has the potential to provide educators with a flexible framework for building engaging virtual learning environments. Teachers can create interactive classes, virtual field trips, and team projects thanks to seamless accessibility across platforms and personalization choices. Real-time user involvement and communication encourages social interaction and critical thinking abilities. With the help of *Mozilla Hubs*, teachers can design interesting

‡‡ https://www.tiltbrush.com last accessed 2024-03-15

§§ https://www.meta.com/en-gb/experiences/3438333449611263 last accessed 2024-03-15

¶¶ https://hubs.mozilla.com last accessed 2024-03-15 and welcoming online learning activities that encourage participation and deeper understanding. While both, Mozilla Hubs and our tool, offer browser-based approaches to synchronous collaboration, there are distinct advantages:

One key advantage is the extensive synchronous object manipulation it provides. Unlike *Mozilla Hubs*, our tool allows real-time, synchronized object manipulation where changes made by one user immediately affect what others see. This offers a more immediate form of interaction that is not present in the same way in *Mozilla Hubs*. Additionally, our tool offers advanced features such as collision detection, complex animation capabilities, and conditional logic, providing users with a wide range of possibilities for creating interactive experiences.

A second mayor advantage is the extensive programmability. *Mozilla Hubs* has only limited programmability capabilities, offering users few options for customization and advanced scripting. By leveraging the programmability of our tool, users can unlock a world of possibilities and truly personalize their VR-based remote learning environments, enabling educators to create new script add-ons and extend its functionality to suit their specific needs.

3. Methodology

Making extensive use of existing WebXR the VR teaching tool introduced in this paper offers a rich set of features that enhance the learning experience, encourage collaboration, and enable interactive remote learning. Some of those features include:

- WebXR Technology and THREE.JS: Because the tool was created using WebXR and the THREE.JS library, it can easily integrate with web browsers without the need for additional software installations, providing users with a more user-friendly experience without compromising graphical capabilities.
- Multi-platform Compatibility: The tool is made to operate seamlessly on a variety of VR headsets, from entry-level models to high-end gadgets, enabling accessibility for a broad spectrum of consumers.
- Real-Time Database Communication: By integrating Firebase Real-Time Database, information such as object positions can be stored and retrieved quickly, efficiently, and in real-time, ensuring synchronized user experiences.
- Programmatic Extensibility: capability for easy script extension, enabling us to modify and enhance its functionalities.

While our tool is designed to run on high-end VR headsets such as Oculus Rift and HTC Vive, we placed particular emphasis on ensuring its performance and functionality on more affordable headsets like Google Cardboard to ensure that the VR teaching tool remains accessible to a wider range of users, allowing them to experience the collaborative immersive virtual learning environment without the need for expensive hardware.

The WebXR API Emulator, see Figure 1, offers users the capability to run WebXR applications responsively on their desktop browsers, even in the absence of XR devices. The extension not only provides this functionality, but it also includes multiple available devices for testing purposes. Users have the flexibility to switch between emulated devices, each offering varying degrees of freedom and number of controllers. Currently, the distinctions between these devices lie in their degrees of freedom and the number of controllers they simulate. By utilizing this extension, users can conveniently run WebXR applications on their desktop browsers, even without the requirement of any XR (Extended Reality) devices. By leveraging the WebXR API Emulator, we were able to ensure that teaching tool delivers a seamless and immersive experience across a variety of VR hardware platforms.

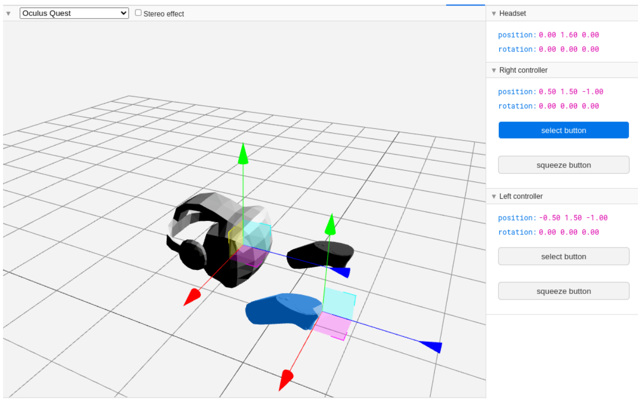

Figure 1: *WebXR API Emulator Emulating Oculus Quest VR Headset*

Our VR tool was developed using JavaScript, a common scripting language that operates in web browsers. In order to create 3D scenes, objects, and interactions, we utilize the powerful THREE.JS library, which offers a complete range of tools and features that make working with 3D graphics easier. By providing pre-built components including scenes, cameras, geometry, materials, and lighting, the library abstracts away the difficulties of WebGL development. THREE.JS offers a large variety of built-in geometries and enables loading external models made with 3D modeling software. It also offers a variety of materials with colors, textures, and reflective qualities to define how objects look. The event handling features of THREE.JS also include user interaction, collision detection, and physics simulations. It smoothly integrates with HTML, CSS, and JavaScript frameworks, among other web technologies. Overall, THREE.JS makes it easier to develop dynamic and aesthetically pleasing 3D visuals for web apps. It is a popular option for developers creating 3D content because of its vast documentation, great community, and variety of capabilities. Developers can make their imaginative concepts come to life and improve user experiences with amazing 3D visualizations with THREE.JS.

In order to enable virtual reality capabilities within our tool, we extend the functionality of THREE.JS using the WebXR API. WebXR is an API that allows developers to access and interact with virtual and augmented reality devices through web browsers. The WebXR Device API serves as the core of WebXR, managing the selection of output devices, rendering scenes at appropriate frame rates, and handling motion vectors from input controllers. WebXR-compatible devices range from immersive 3D headsets and AR eyeglasses to mobile phones that augment reality through camera-captured scenes. Key capabilities of the WebXR Device

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API include finding compatible VR or AR output devices, rendering scenes with proper perspective, optionally mirroring output to a 2D display, and creating vectors to represent input control movements. Scenes are presented in 3D by computing perspective for each eye's viewpoint and rendering the scene accordingly. The resulting image is delivered to the WebXR device for presentation through headsets or other display devices.

To ensure synchronous and real-time collaboration between students and teachers, our tool integrates Firebase Realtime Database. Firebase Realtime Database is a cloud-hosted NoSQL database that provides real-time data synchronization. The Firebase Realtime Database's main features are real-time data synchronization, offline functionality, and client device accessibility. Real-time synchronization eliminates the need for manual network code implementation by enabling quick updates to connected devices whenever data changes. The Firebase Realtime Database SDK ensures app responsiveness even when offline by persisting data locally and synchronizing any missed changes once connectivity is restored. This offline capability enhances user experiences by providing seamless data synchronization. Direct access to the Firebase Realtime Database from mobile devices and web browsers eliminates the requirement for an application server. Security and data validation are supported through Firebase Realtime Database Security Rules, which are executed when data is read or written. The Firebase Realtime Database offers a cloud-hosted, real-time data storage solution with built-in synchronization, offline functionality, and accessibility from client devices. It simplifies data management, enhances user experiences, and provides scalability for cross-platform applications.

In the implementation of our VR tool, we make use of essential three.js libraries to enhance the functionality and capabilities of our project. These libraries include:

- THREE.JS: We import and utilize the entire three.js library by using the THREE object. This library serves as the core framework for creating and rendering 3D scenes, objects, and interactions.
- OrbitControls: We import the OrbitControls library, which provides basic scene manipulation functionalities such as panning, zooming, and orbiting around objects. This allows users to navigate and explore the virtual environment with ease.
- VRButton: The VRButton library is imported to enable the VR mode in our application. By utilizing this library, we provide users with a button that allows them to enter the immersive virtual reality experience.
- XRControllerModelFactory: We import the XRControllerModelFactory library to facilitate interactions with controllers and grips. The tools and functions required for handling controllers and the models that go with them within the virtual environment are provided by this library.

4. Example lecture: An introduction to curve representations

To demonstrate our tool, we created a simple lecture which provides the students with insight to curves typically used in a computer aided design environment.

In THREE.JS, curves are mathematical representations of continuous paths in a 3D space. Curves are defined by a collection of control points that affect the curve's trajectory and shape. Depending on the kind of curve, a specific interpolation algorithm is employed. Control points play a pivotal role in our VR tool, as their positions are stored in the database in real time. This enables the synchronous and real-time control of curves, as well as other objects within the virtual environment. THREE.JS provides a variety of curve classes, each with its own characteristics and properties. Some of the commonly used curve classes include LINECURVE3, QUADRATICBEZIERCURVE3, CUBICBEZIERCURVE3, and CATMULLROMCURVE3. Each class is designed to produce a certain kind of curve with varying levels of smoothness and complexity.

Users will have the ability to manipulate the control points by dragging them within the virtual world. As the control points are moved, the curve updates dynamically, adapting its shape and trajectory accordingly.

To enhance the flexibility and expandability of our VR tool, we have created a separate method specifically designed for handling objects, such as curves. This strategy makes it simpler to implement other objects, not just curves. We can quickly expand our technology to include different sorts of objects by modularizing the object generation process, giving educators a flexible framework for designing engaging learning activities. The modular object method provides effective and smooth integration of many aspects into the virtual world, be they curves, forms, or other educational content.

The WebGLRenderer handles the rendering of the 3D scene onto the user's device. To produce an immersive visual experience, it makes use of WebGL, a JavaScript API for rendering dynamic 3D and 2D graphics. To enable VR capabilities in our tool, we utilize the renderer's XR (WebXR) feature. WebXR is an API that provides access to VR and AR devices through web browsers. Developers can build immersive XR experiences using the methods, events, and objects provided by the WebXR Device API. The WebXR Device API gives developers a uniform interface to work with by abstracting the underlying hardware and software complexity of various XR devices. Numerous XR devices, such as VR headsets, AR glasses, and mobile devices with AR capabilities are supported by it.

THREE.JS's WebXR API comes with built-in controllers. By attaching event listeners to the controller, we can respond to user input and trigger specific actions or behaviours in the virtual environment. The event listeners are configured in this case to handle the start and end of the click action. The event listeners can be modified to meet unique interaction needs.

The controller grip was added to the VR scene. The controller grip is a 3D representation of the input device or joystick in the virtual environment. By adding the controller grip with its corresponding model, we enhance the visual representation of the input devices in the virtual environment. We also establish a visual depiction of the ray being projected from the controller onto the scene by attaching the geometry line as a child to the controller object. This line aids in user interaction with virtual environment objects by acting as a visual indicator for the user.

The matrixWorld property plays a crucial role in our implementation, particularly because when objects are attached to the controller, we cannot determine their position through any other means than by using matrixWorld. We store the objects' matrixWorld positions in the database whenever the teacher moves them. When the position changes, the updated data is sent to the student's scene, and the objects are moved accordingly based on their new positions in the matrixWorld. This enables real-time synchronization between the teacher and the student, ensuring that the object's movements are accurately replicated in both scenes.

We utilized the power of Firebase database for maintaining object position synchronization among connected users, since the location of the contact point on the curve is stored in it. In other words, the position of the curve itself, as well as every other object in the scene, is determined by the position information kept in the database.

5. Results

To effectively showcase the outcome of our research, we provide a detailed demonstration of our synchronous, browser-based VR remote teaching tool in action. By presenting the tool's functionality and its practical usage, we can offer insights into its capabilities and highlight its potential impact on remote teaching experiences. Therefore, we will provide a step-by-step guide on the usage of our tool in a example scenario shown in Figure 2:

Both the student and the teacher open their web browsers and go to the hosted website URL before entering the VR learning environment. Within this immersive virtual space, the teacher takes on the role of the facilitator, selecting an object to showcase in the scene. In our specific implementation, we utilize a 3D Catmull Rom Curve as a test object. By placing control points along the curve, the teacher has the ability to manipulate its shape and form.

Any adjustments the teacher makes to their scene immediately appear in the student's scene. Figure 3 shows six instances of the modified curve. The student may view the results instantly on a hand held phone, as shown in Figure 3, or using XR Glasses. These adjustments, such as shifting a contact point to alter the curve, are seamlessly repeated, creating a collaborative learning experience for both the teacher and the student.

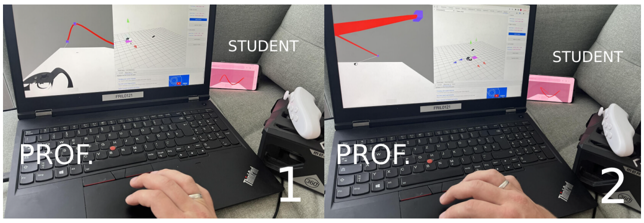

Figure 2: *Synchronous movement of curve on student's screen as teacher modifies the curve.*

Students are given the opportunity to observe the curve from a variety of angles and perspectives as they explore the virtual landscape, which helps them better comprehend its characteristics. Furthermore, with the teacher's permission, students can actively engage with the curve by interacting with its contact points. Any adjustments or movements made by the students are instantly mirrored in the teacher's scene, creating true collaboration in the remote learning setting. The example shown in Figure 4 students where asked to fit the curve to the contour of the vase, giving students the experience of how these different curves behave. The task at hand may equally be to create a rotational surface, which may be demonstrated by the teacher, who then engages the students to reproduce what has been explained. If problems are observed, the teacher can interact with the same curve to, again, demonstrate and explain the task.

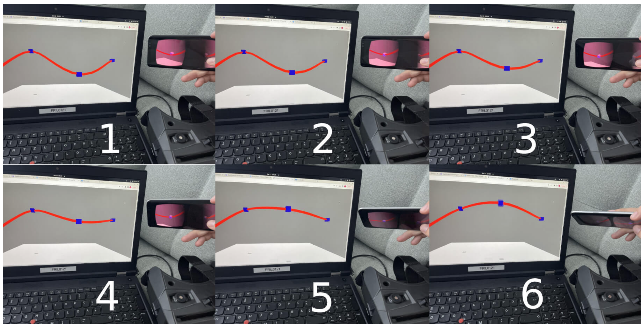

Figure 3: *Movement of curve on teacher's screen as student manipulates the curve.*

Figure 4: *An example student task involved outlining a rotationally symmetric object during class.*

To encourage modelling with these curves, students are asked to outline 3D shapes placed in VR. In case of difficulties, the teacher may collaborative help with this task by manipulating the curve to demonstrate on how this may be achieved.

The feedback in initial trials was positive throughout from students and teachers alike. We are aiming to conduct a thorough evaluation in due course to evaluate through usability testing, surveys and questionnaires on various aspects of the interface.

The authors are unaware of any interactive XR interface which matches the capabilities of the system presented here.

The possibilities of the teaching tool extend beyond 3D curves through script extension, allowing the teacher to add any desired object.

6. Conclusion

We present an implementation of a synchronous, browser-based VR remote teaching tool, which surpasses the capabilities of typical remote teaching methods and provides teachers with a new way to engage students in meaningful remote learning experiences. The browser-based VR application presented in this paper offers a collaborative VR environment for educators to engage students in a VR environment.

Due to its affordability and accessibility, it replaces the need for expensive and specialized equipment by having only a few system requirements and allowing access through a web browser, making VR-based remote education more widely available.

The script extension of our tool allows teachers to quickly add any required object to the virtual environment, thereby creating a more user-friendly and intuitive interface. As a result, more customization and flexibility would be available, enabling teachers to adapt the VR learning experience to specific learning and teaching objectives.

The tool facilitated active participation, knowledge acquisition, and interaction, creating immersive and interactive learning experiences. By providing cross-platform accessibility and compatibility with budget VR equipment, the tool democratizes educational VR, making it accessible to a wider audience.

The browser-based VR teaching tool presented in the paper offers a promising solution to bridge the gap in remote education, enabling an immersive, interactive, and accessible remote learning environment. The tool provides cross-platform accessibility and compatibility with budget VR equipment, making it accessible to a wider audience.

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