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EduVR Collab: A tool for management immersive collaborative learning

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Abstract: Improving education through virtual reality is challenging due to the high costs of developing systems and the lack of teacher engagement in project conception. This project introduces and evaluates a system that enables teachers to create their own lessons in virtual reality without prior programming knowledge, addressing these challenges. By integrating Learning Management tools, Learning Analytics, and Multi-user Connection Servers, we developed a system that allows multiple users to coexist in the same virtual environment and perform various tasks. Our system also enables educators to evaluate students based on their behavior. In EduVR, teachers can configure activities in advance and retrieve results. Heuristic evaluations of EduVR's integrated environment design have demonstrated its potential as a model for developing new educational platforms, setting a new standard for virtual reality educational systems.

Keywords: virtual reality, technology-enhanced learning, learning analytics, immersive learning, multi-user

1 Introduction

The technology used in teaching and learning has led to the concept of technology-enhanced learning (TEL) [Kirkwood and Price, 2014]. However, a technology discussion with a user-centric approach provides a complete process view. According to Laurillard [2007], TEL is crucial to personalize the teaching and learning processes, improving their quality and effectiveness.

TEL-based systems require continuous user feedback. Teachers need feedback to continuously improve their activities, while students need feedback to monitor their progress. This feedback is a critical aspect of the effectiveness of technology in education. Most Educational Systems created in Virtual Reality base their foundations on creating an environment where the student can be evaluated in gamified ways, disregarding their interactions when grading. These systems only evaluate a single user at the time, and the teacher does not participate in the Virtual reality.

Therefore, we propose a novel architecture to evolve the prior systems, integrating multi-user tactics for students and tutors to interact concurrently with the environment. The proposed systems estimate and analyze these interactions within a personalized learning system developed in virtual reality. Drawing upon theoretical concepts from Learning Analytics, Human-Computer Interface, and Education, we envision a multi-user interactive ecosystem, seamlessly integrating personalized learning and learning analysis.

By enhancing pedagogical aspects with technology, we create a system that provides a collaborative learning experience, allowing educators to monitor students' behavior and personalize the content in an immersive environment.

Our proposed system explores part of the design recommendation listed by Paulsen *et al*. [2024]. We integrate a learning management system (LMS) into an immersive environment and explore multiplayer features to provide collaborative learning. We designed the proposed case study with a stakeholder. We built a chemical lab for students' spatial interaction. Our architecture provides a log module to collect students' behavior and give its perspective to educators.

Our system is called EduVR Collab. Its functionalities empower educators to tailor the teaching environment according to individual needs and to receive precise and concise evaluations of their students' performance, irrespective of their prior computing knowledge. blue Consequently, the primary objective of this project is to introduce a new architecture for evaluating users through organized interactions in a personalized learning environment, leveraging the potential of virtual reality technology for education.

This paper builds upon the work presented in Viol *et al*.

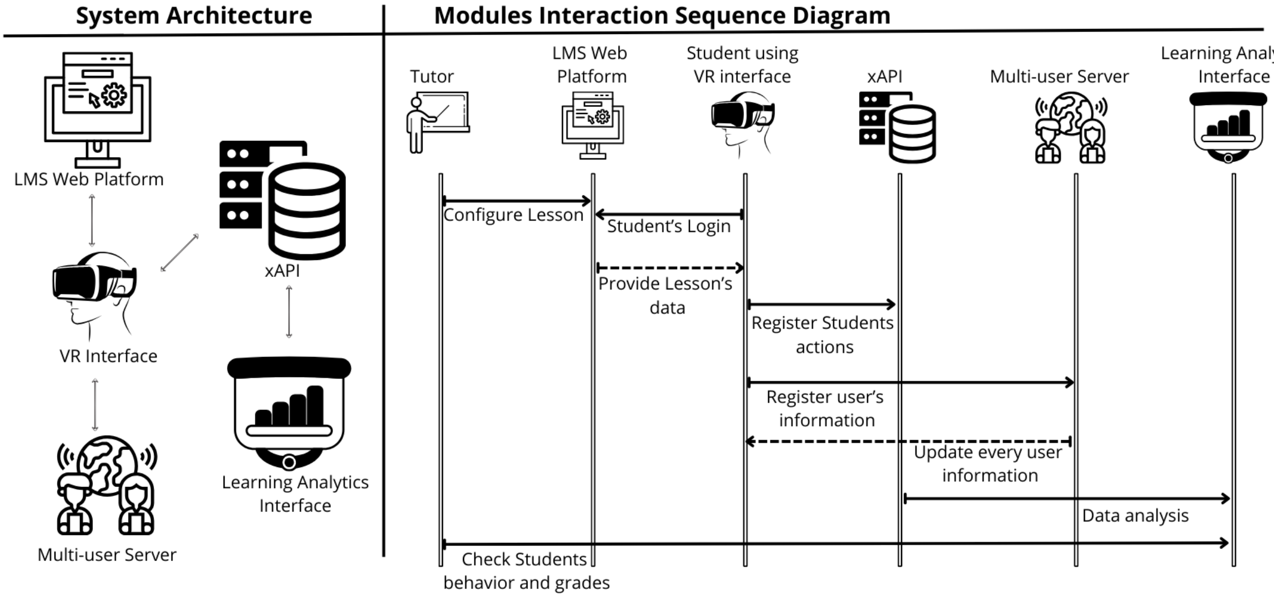

Figure 1. System Architecture and Modules Integration Flow.

[2023], enhancing the original EduVR system with multiplayer tools that broaden the scope of tasks teachers can design to assess their students. Furthermore, we evaluated the system using virtual reality heuristics with two authors and Stakeholders. Additional experiments with end users are not the focus of this paper. In future work, we plan to perform user studies after getting approval from the local ethics board. The paper contributions are:

- To develop an educational system in Virtual Reality where teachers can create lessons without programming knowledge.
- To develop a system in which the results of the interactions among students and the lessons are captured and translated into information data for the teachers.
- To improve the system into a collaborative environment where students and teachers can interact with each other through voice and gestures to advance through the lessons.
- To evaluate the designed usability through a heuristic evaluation application to stakeholders, highlighting crucial points on the VR environment.
- To discuss challenges in creating both multi-user and educational systems.

The rest of this paper is organized as follows: Section 2 discusses theoretical references that guide this work and related works and how they connect to the proposed environment. Section 3 discusses stakeholders and functional and nonfunctional system requirements and the system proposal. Section 4 presents the techniques used to integrate multiuser environments. Section 5 displays a study case developed as a proof of concept for this application. Section 6 presents a heuristic evaluation of platform design. We highlight multiuser constructions specific challenges and achievements in Section 7. We discuss the lessons learned for constructing educational systems through the design process in Section 8. Finally, Section 9 presents the conclusion.

2 Theoretical References

This section assesses the main concepts within the context of Active Learning and its assessment. It begins by discussing the relationship between active methods and personalized learning. We discuss technology integration into the education system , and the importance of analyzing learning technologies and their challenges is concluded. Furthermore,we present some important aspects of Social presence. Finally we discuss the heuristics for virtual reality.

2.1 Active Learning

Comprehending the learning process is a complex task that encompasses various approaches. In traditional teaching, for example, the learning process revolves solely around the teacher, as noted by Säljö [1979].

In this model, the teacher conveys all knowledge while students passively receive it within the classroom limits. Its knowledge transmission is one-sided-oriented, with students depicted as passive roles. However, with the arrival of information globalization, students now have access to alternative means of acquiring previously restricted knowledge. Consequently, teachers should revisit their roles. As students can actively pursue knowledge, teachers must find new ways to teach, assuming guidance in students' pursuit of knowledge. This student-centered teaching approach has given rise to tools development that enables and directs students' exploration [Crisol-Moya *et al.*, 2020]. This methodology is known as Active Learning.

This methodology lets teachers focus on each student's individuality and identify learning differences. Personalized learning involves adapting methods and instructional systems to meet the unique objectives of each student [Pane *et al.*, 2015]. It entails evaluating the student's difficulties and abilities, providing appropriate activities to fast-track learning, and benefiting from the student's strengths while addressing weaknesses.

Armbruster *et al*. [2009] describe how implementing a student-centered pedagogy in a biology course enhances academic performance. Authors emphasize crucial elements such as presenting course content in a new way, incorporating interactive learning activities and problem-solving tasks, and fostering an environment centered on student learning.

Research on student-centered pedagogical approaches consistently demonstrates that active learning methodologies lead to significant improvements in student performance compared to traditional methods. In Science, Engineering, and Mathematics courses, the adoption of active learning strategies has been shown to increase the proportion of students achieving top grades from 50% to 68%. Additionally, these approaches have reduced the rate of errors in assessments, with error rates dropping from 33.8% to 21.8% [Freeman *et al*., 2014].

2.2 Enhancing Learning with Technology

Technology has emerged as a valuable asset in reshaping traditional teaching methods. It empowers teachers by offering support in developing innovative educational tools that personalize knowledge for students and transcend the confines of the conventional classroom. Simultaneously, it helps students comprehend and retain concepts more effectively, giving them greater access to readily available, up-to-date content.

Technological device dissemination, such as computers, mobile phones, 3D immersion equipment, and video games, has significantly expanded educators' range of teaching and learning solutions. Here are some unique approaches by Pathania *et al*. [2021]:

- E-learning: This online, self-learning platform allows students to access educational materials from anywhere and receive constant updates. Promote flexibility and convenience in the learning process.
- Massive Open Online Courses (MOOCs): These open-source platforms are valuable for students and teachers, offering opportunities for professional development. Although they provide publicly accessible information, feedback and interaction with instructors can be limited.
- Serious Games: These highly engaging tools captivate users' attention, bringing a sense of enjoyment and transforming study into a pleasurable experience. However, teacher personalization can be challenging since games are not easily adaptable.
- Augmented Reality (AR): AR visualizes virtual elements within a physical domain, enabling students to interact with and observe the world through an AR device.
- Virtual Reality (VR): This immersive technology transports students to a new 3D world to experience enhanced immersion and engagement. It can sharpen users' attention, promote the same sensations of pleasure experienced in games, and offer regulated choices for users.

Each of these possibilities comes with its compensations and shortcomings. These activities generally promote personalization and student immersion and generate better cognitive responses [Bakkes *et al*., 2012; Freitas *et al*., 2010].

2.3 Learning Analysis

A significant obstacle in utilizing technology for educational purposes is effectively assessing the knowledge gained.

The role of educators evolves significantly as new teaching methods emerge. Teachers are now charged with comprehending students' unique learning profiles through the use of personalized learning technologies. This approach enables them to create tailored learning paths that align with and support each student's individual objectives and goals.[Pane *et al*., 2015].

In addition, the teacher must create the proposed activities and define the scope of the learning topics. This feature enhances support for student development on the personalized learning path. The parallel use of personalized learning also makes the teacher responsible for setting the criteria to guide students to the next step on their learning path.

In immersive learning, teachers play a crucial role in designing and facilitating immersive experiences and activities for students, tailoring the content to suit their developmental needs. Just like traditional classrooms, teachers also require feedback on the activities progress they develop. This feedback allows for re-assessment and future improvement of the educational tools.

Developers have employed various Big Data techniques to create an educational system called Learning Analytics [Clow, 2013] to address this challenge of analysis. Learning Analytics involves analyzing, measuring, collecting, and visualizing data related to the learning process, including information about students and the context in which one is engaged [Lang *et al*., 2017]. It encompasses user experiences and behaviors and assists in identifying and validating processes. Furthermore, it supports practices based on evaluating progress, motivation, attitudes, and user satisfaction. [Mangaroska and Giannakos, 2018].

In their search for dynamic data collection solutions for Learning Analytics, [Cooper, 2014], Ángel Serrano-Laguna *et al*. [2017] developed an API for serious games that allows educators to customize predefined actions. Their platform, known as xAPI Profile, provides a method to implement Learning Analytics within an application, enabling data collection from user interactions. Tuparov *et al*. [2018] use this platform to integrate a framework that focuses on the evaluation features. They evaluated how assessment activities, peer assessment, and self-assessment could be implemented on the Moodle platform using xAPI.

2.4 Interactions in Virtual Reality

Imagining a platform that converts data into an experience makes VR a fantastic way to improve communication. When we consider the definition of interactivity [Steuer, 1992] as 'users participating in modifying the form and content of a mediated environment in real-time, it becomes clear that user interactions play a crucial role in developing Virtual Reality. The primary method of interaction in a VR system is translating users' positions and hand movements into a different environment [Spittle *et al.*, 2022]. Speech is also a common form of communication in this technology. However, the potential for engaging the user's senses goes beyond that.

In their review, Kitson *et al.* [2018] catalog 12 different types of design elements used to measure interactions in a VR environment. Among them, breath awareness can make users more aware of their bodies, biofeedback can aid in achieving concentration, and physiological measures such as temperature can provide insights into the user's health. In-game inputs can enhance social presence and emotional expressions. The more connected the user feels to the virtual environment, the more enriched their experience will be. Although users commonly use a headset to provide mechanics for interaction [Spittle *et al.*, 2022], creators can also design environments with handheld displays or multi-display setups.

Multi-user virtual reality systems share the same resources as single-player interactions. The catalog of interactions among users requires careful review and understanding. Previous works, such as Brown *et al.* [2017], Schild *et al.* [2018], Schild *et al.* [2019], Jung *et al.* [2022], Kim *et al.* [2019], Kuznetcova *et al.* [2021], and Wienrich *et al.* [2018], rely only on present current virtual reality systems for multiuser purposes but do not focus on the nature of the interactions. Jerald *et al.* [2017] notes that most interactions occur through voice, but the variety of interactions a user can engage in depends solely on the tools provided by the system.

2.5 Collaborative Learning

Collaborative Learning involves groups of learners interacting to solve a problem with educational purposes Laal and Laal [2012]. Two or more students should perform activities in collaboration for a common goal. This process involves more than a teacher presentation and explanation of content. It requires a more active learning role from students who should perform actions toward solving an educational issue. The process can help students learn from each other in groups. Teachers have the role of monitors, observing the students' behavior and difficulties and giving them directions for learning.

Computer-supported Collaborative Learning (CSCL) is the collaborative learning process mediated by computational artifacts Ludvigsen and Mørch [2010]. It can be used in online tools and performed synchronously or asynchronously. Digital Games play an effective role as a CSCL with the potential for promoting student engagement through actions, rules, and other parameters for players Wang and Huang [2021].

Virtual reality is an immersive environment with rich spatial information and embodiment interaction that can provide gamification aspects. It is a significant tool for collaborative learning [Back *et al.*, 2020; Paulsen *et al.*, 2024; Zheng *et al.*, 2018]. Paulsen *et al.* [2024] state design recommendations for VR CSCL systems in some fields, among others.

- **Pedagogical and technical aspects**: Align the pedagogical goals with the technical features and include stakeholders in designing and evaluating immersive environments.
- **Social Interaction on Immersive Environments**: Avatars should be recognizable and customizable, providing an embodiment perception for users.
- **Degree of realism**: The interaction should be more realistic and explore the spatial aspects of the technology. Although 360-degree videos are an alternative, they are limited to non-scripted interaction.

Next section discusses social presence aspects for multi-user systems.

2.6 Social Presence

Commonly, experts define multi-user systems as platforms that enable concurrent usage and participation by multiple users. In the realm of virtual reality, these systems create a distinct layer of interaction, fostering nuanced interpersonal dynamics among users.

Although single-user systems focus on individual interactions within the virtual environment, such as navigation, interaction, and manipulation [Philippe *et al.*, 2020], multi-user systems extend this paradigm by incorporating interpersonal interaction among users. This enhanced form of interaction fosters the development of social presence within virtual environments and facilitates the emergence of novel social relationships among participants [Johansson and Roupé, 2022].

This shared experience engenders a heightened sense of co-presence, wherein users perceive themselves as coexisting with others in the same virtual space, thereby giving rise to diverse forms of presence. Schultze [2010] categorizes these forms into six distinct types:

- Telepresence: The perception of being present in a remote location.
- Social Presence: The sense of being in the company of others within the virtual environment.
- Co-presence: The feeling of being together with others in a distant space.
- Autopresence: The sensation of inhabiting one's virtual body.
- Hyper-presence: The impression that one's authentic self is immersed in the virtual environment.
- Eternal Presence: The feeling of being connected to others, even in solitude.

The complex link among these presence types' development and users' virtual representation within these environments, commonly referred to as avatars, is evident. [Pakanen *et al.*, 2022]. Avatars may range from abstract representations to lifelike human figures, with the degree of customization directly influencing user engagement [Gorisse *et al.*, 2017]. Personalization of avatars fosters a sense of self-presence and embodiment among participants, thereby strengthening their connection to the virtual environment.

Embodiment, as conceptualized by Schroeder [2001], denotes integrating of one's physical self with digital representation, emphasizing the social context in which avatars exist. Hence, well-developed multi-user virtual reality systems must provide users with the following features:

- To offer a wide range of avatar customization options to improve your online presence and promote a user engagment.
- To design environments rich in detail [Pan *et al*., 2006] that facilitate user interaction, thereby enhancing telepresence.
- To provide visualization of someone else's avatar, including their spatial location, gestures, and interactions with the environment, thereby promoting co-presence and social presence.

2.7 Gamified Learning Environments

In the current state of the art, Gamified Learning Environments are feasible and present lots of advanced innovation. A common approach is to employ gamification elements in learning environments to create challenges and emotional triggers that motivate users. Badges and points frequently quantify learning progress [Dichev and Dicheva, 2017]. Incorporating these components provides a sense of progression, which helps motivate users to continue their learning journey. However, we must consider how to build engagement, as typically, this educational setting does not evaluate students' motivations. [Dichev and Dicheva, 2017]. Many projects create evaluations solely for grading purposes, with less emphasis on understanding user interactions and motivations. Additionally, most projects adopt a unique scenario-based approach, which only their users validate and is not easily reusable. More information about how instructors and designers choose and integrate game elements into these projects [Khaldi *et al*., 2023].

In order to advance the current state of the art, This project seeks to create an environment where we evaluate progress not only based on grades but also by taking into account all interactions to establish a comprehensive knowledge pathway. Furthermore, by developing a flexible setting that can accommodate multiple activities, we aim to address the primary issue highlighted in the review by Khaldi *et al*. [2023] regarding gamification.

2.8 Heuristics for Virtual Reality Evaluation

Experts employ evaluation heuristics to assess and identify interface design issues that may compromise user experience. Their application highlights the most relevant problems and their severity in the evaluated systems.

Recognizing that traditional heuristics such as Nielsen's heuristic evaluation [Nielsen, 1992], cooperative evaluation with users to diagnose problems [Monk *et al*., 1993], or cognitive walkthroughs [Wharton *et al*., 1994] may not detect issues intrinsic to virtual reality—such as interaction with the environment, control consistency, and the need for high fidelity, researchers have developed new heuristics for application in these environments.

Evaluation heuristics are methods employed by experts to assess and identify interface design issues that may compromise user experience. The results of their application highlight the most relevant problems and their severity in the evaluated systems.

Classic heuristic evaluations like Nielsen's heuristic evaluation [Nielsen, 1992], cooperative evaluation with users for diagnostic purposes [Monk *et al*., 1993], and cognitive walkthroughs [Wharton *et al*., 1994] might not uncover problems unique to virtual reality environments, such as issues with environmental interaction, control consistency, and the demand for high fidelity. Consequently, new heuristic approaches have been formulated specifically for these virtual settings.

Sutcliffe and Gault [2004] proposed a model that evaluates the naturalness of the environment and actions and the clarity of activities performed. Additionally, Murtza *et al*. [2017] introduced a heuristic that assessed movement synchronization and headset comfort. Finally, Guo *et al*. [2024] build upon evaluation heuristics [Nielsen, 1992] and includes previous heuristic specificities. This heuristic will serve as the basis for evaluating this project, as detailed in Section 6.

Some articles employ these heuristics techniques to evaluate and improve their work, as Tanaka *et al*. [2023], that created an environment in Virtual Reality for electrician training and evaluated their system receiving 19 usability issues, grading from cosmetic issues to major problems.

3 System Proposal

The system's development used shared design techniques, in which all members contributed to full archive development. The stakeholders - teachers, students, developers, and institutions - participate in the conception from the process beginning. Whereas teachers, e.g., act like co-designers in the conception process, the students generate data that create patterns for machine learning.

3.1 Stakeholders

The system conception identified three different stakeholders. Each one possesses their expectations that the team watched during the conceiving process.

1. **Teachers:** The system must create accessibility for the teachers to make it possible for them to adapt it to their activities throughout the development platform. So, it needs to be operative even without the development team's participation, and the teachers must be able to benefit from it even if they do not possess any programming knowledge.
2. **Students:** The system has to be capable of providing adapted tools to the students. These tools [Pan *et al*., 2006] must promote students' motivations and reflect on the positive results in the learning process.
   Not less, it must integrate tools to allow students to choose their avatars when diving into the classroom. This avatar is required to represent the spatial position of the student and has to possess tools for communication among students.
3. **Institution:** The platform must generate results on the learning evaluation and be capable of self-adapting to the student's level to create a complete trajectory of knowledge development. It also has to provide a way

for students and teachers to share the same space in virtual reality, recreating an environment close to a real classroom.

The evaluations taken from students' interactions aim to implement a robust learning analytic system that automatically captures user interactions within the learning environment. This system should provide valuable insights to the teachers and researchers operating the platform, enabling them to track activity development and gather data for comprehensive analysis.

Furthermore, our proposal seeks to identify individual "paths of knowledge". By understanding how learners behave during the learning process, we can create personalized suggestions for interactions that maximize each individual's learning potential. This approach aims to optimize and tailor the learning experience to each learner's needs and preferences.

The stakeholders' proposed needs based the EduVR requirements, and the following Sections will present them.

3.2 Non-Functional Requirements

A web platform integrates the system, where teachers include and manage multimedia micro-services such as uploading videos, photos, or texts for students. These micro-services interface with the web platform and the game's tasks. The classroom's development system through VR adaptation games should use Unity's engine. All implemented queries between both systems will use JSON (JavaScript Object Notation) [1], a lightweight data-interchange format.

The system will also integrate a multi-user-oriented data server that must provide the foundation for recreating the same environment for each user.

3.3 Functional Requirements

The web platform must have a simple and familiar interface for the tutors, allowing them to upload resources that will integrate the VR classroom. These adaptations will make every classroom unique for each teacher, promoting the reuse of the already-created spaces. This technique makes the classroom programmable without programming.

The results of users' interactions with the proposed evaluations created by teachers must return through distractors [Gierl *et al.*, 2017], to evaluate the students for the complete learning received and discard possible problems due to fatigue, emotional issues, or learning disabilities.

Objects and avatars on the scenes must have their positions streamed through the system to every user. The interaction's result between one user and the environment has to be chained to other users to create a shared experience space for the users. The user's gestures and movements in VR must represent real-world movements and be steamed to others, giving all users representations close to real life in VR.

[1]https://www.json.org/

3.4 Proposed Architecture

This Section presents the application components, their technologies, and their roles. We described how we manipulated each technology to build each component. Teaser Figure 1 shows the system architecture. We have developed a version that is compatible with VR, supporting both HTC VIVE and Oculus Quest devices, alongside a non-VR model designed for experimental uses. However, they are both exclusively limited to running on the Microsoft Windows operating system.

- **Learning Management System (LMS).** The LMS is a standard system used to connect educators and students. An LMS provides an interface for educators to manage the lesson content and for students to manage their advances. It can be used for remote or face-to-face lessons. Moodle [2] is an example of LMS used by many educational institutes for learning purposes. Learning Press [3] is also an open-source plugin based on Word Press [4] content management platform that contains several plugins. It also includes a course page with a structure for visualizing the offered courses. Although we are still not using this resource, we decided on Learning Press as an LMS for our proof of concept, given this project's purposes and next steps. Figure 2 shows our LMS web platform screen.

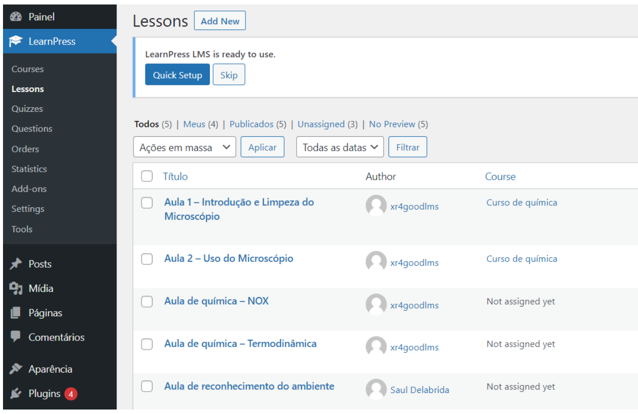

Figure 2. Developed LMS.

The WordPress web platform and Learning Press plugin provide the interface. The project team customized the communication between the LMS and VR systems, but an API accessed by a URL retrieved most of them. The LearnPress panel provides an interface to create and manage courses, lessons, quizzes, and questions. An educator must submit all content through this interface. It is essential to state that the statistic modules are from the LearnPress system and do not correspond to our Learning Analytic interface.

- **VR Interface:** The VR interface is a developed 3D interface that provides users an immersive experience to enjoy in practice. It is widely acknowledged that today's technology still demands a solid grasp of com-

[2]https://moodle.org/
[3]https://wordpress.org/plugins/learnpress/
[4]https://wordpress.org/

puter programming. However, it is concerning that many educators are not adequately equipped to perform this skill. The system should be capable of providing a 3D scenario for educators to integrate lesson content through customized 3D components. These designed components should receive and process educators' data, reflecting the LMS interface configuration. Based on our 3D customized components on the most common multimedia components. We developed using the most common multimedia components used by educators. Next, we describe the implemented components.

Slider Component: The Slider Component shows the images loaded by the educator on the LMS system. It comprises a screen to show images and two buttons for the student to navigate among the images. Figure 3 shows an example of a slider component on the 3D scene.

Figure 3. Slider Component.

Video Component: The Video Component shows a video loaded by the educator on the LMS system. It comprises a screen showing the video and two buttons for the student to play/pause and repeat the content. Figure 4 shows an example of a video component on the 3D scene.

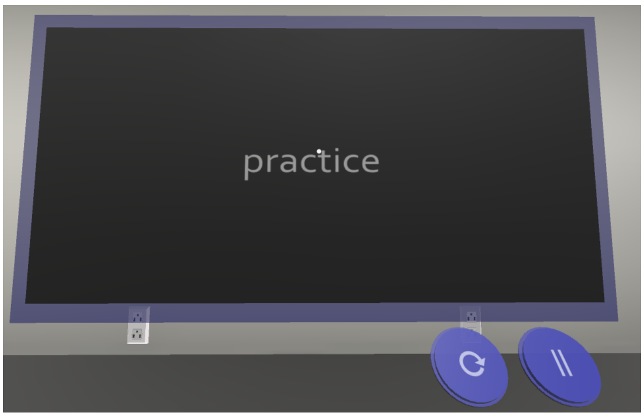

Figure 4. Video Component.

Quiz Component: This component shows the questions the educator inserts into the LMS system and attaches them to a lesson. It comprises a screen showing the questions and possible answers and four buttons for the students to choose their responses. Figure 5 shows an example of a quiz component on the 3D scene.

Figure 5. Quiz Component.

Lesson Instructions Component: The Instruction Component shows the lesson instructions inserted by the educator on the LMS. This version's shape is a whiteboard, and there is no interface for user interaction. Figure 6 shows an example of a Lesson Instruction component on the 3D scene.

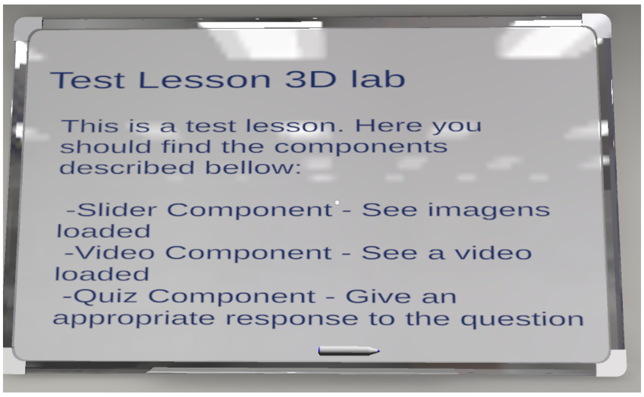

Figure 6. Lesson Instruction Component.

The team developed other components, such as an audio component. In this paper, the team restricts to showing only the available components. Furthermore, all components with user interaction collect action-related data to track the user behavior on the application. The following section describes the xAPI interface used for this purpose. The team developed a system using Unity3D software.

- **xAPI Storage:** The Experience API (or xAPI) is part of the Training and Learning Architecture that an advanced distributed learning project developed. Originally named Tin Can API, the xAPI is an open-source specification for digital teaching applications. A specification collects data and information about these applications' learning and user experience, either online or locally [Lim, 2015]. An xAPI security group provides a set of guarantees for warranty and replacement over activities. The standard declarations form is (actor, verb, object) [Secretan *et al.*, 2019]. For instance, “John read the document on food”. The data is combined using the JSON format. A *Learning Records Store* (LRS) is a server responsible for receiving, storing, and providing access to Learning Records. LRS stores and retrieves xAPI assertions, stores xAPI states, and saves various other related metadata[5]. ScormCloud [6] receives claims registered by xAPI. Furthermore, it has a pre-configured interface for data visualization. It uses MySQL[7] as a database and checks before inserting if the data submitted matches the xAPI proposal. Figure 7 shows an example of the registered data captured from the user interaction with the components.

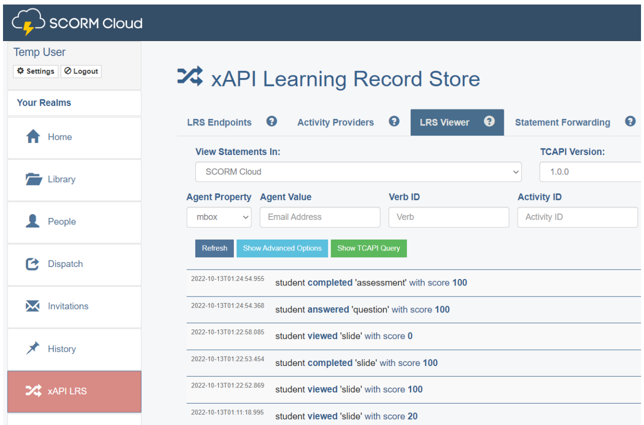

Figure 7. User behavior registered on ScormCloud xAPI interface.

- **Learning Analytics Interface:** This interface is still under development because the team needs to collect more user data to create it. At this stage, the system requirements were defined and customized with the LMS system. We generated a synthetic database respecting the structure of the xAPI as shown in Figure 7 to achieve these requirements. Figure 8 shows a graph example generated by our synthetic dataset.
  The bars show students’ time on each slide loaded on the slider component. The red line represents the average time other students spent using the system. This figure is a single representation of a visualization that helps the educator decide or have more knowledge about the student and their behavior. Researchers and practitioners can explore other visual information and techniques for future applications, such as data science. Also, the user’s spatial movement in the scenario can provide visual information about their movement during the lesson development through a heat map graph, for example.

3.5 Modules Interaction

This section describes the system module interaction flow. Figure 1 shows a sequence diagram illustrating the flow. The

[5]https://xapi.com/learning-record-store/ - Accessed on March 2021
[6]https://scorm.com/
[7]https://www.mysql.com/

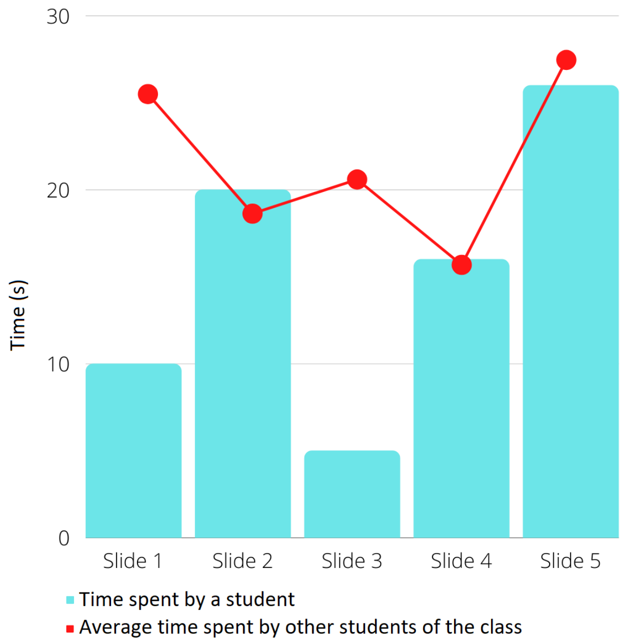

Figure 8. Example of a graph generated by our synthetic data set.

diagram presents two actors: the educator, who can create content for learning, and the student, who can use the VR interface for learning purposes. The educator should access the LMS interface to create a course and its lessons according to the description provided in Section 3.4. A student using the system should log in and select the available lessons.

With the success of this process, the LMS system retrieves all metadata configured by the educator to the immersive interface. When the student interacts with the components described in Section 3.4, their data are uploaded to the xAPI Interface, in this case, the ScormCloud platform. After finishing the lesson, the VR system should register this in the LMS interface. Depending on the interface, it can also be on the xAPI Interface—for instance, the Quiz component registry when the student completes the quiz. Once the students finish their lessons, the educator can check their grades and results on the LMS interface. The Learning Analytics Interface should provide a friendly interface for checking student behavior.

4 Multiplayer features

Creating a collaborative system for education requires observing students and teachers through the process. Learning must not be construed solely as a unidirectional process wherein the expectations of educators are to be met unquestioningly by students. It also has to rely on the understanding that people learn from observing others, from getting advice, by replying to others.

Bringing this knowledge to a virtual reality environment means that the interface should provide all types of communication for users to achieve a lifelike environment. Providing systems that make it possible for students to communicate through their voices, body orientations, and appointments replicates basic life communication.

Doing that in Virtual Reality is a complex task. Since each piece of equipment requires a single application running and each application can only be stated in a single piece of equipment, creating multi-player systems requires the introduction of online servers to manage replication of the information to every instance of VR device simultaneously.

This section describes how EduVR implements its collaborative system in virtual reality, enlightening the same issues found and the solution that the team applied.

4.1 Multi User server

This project includes a data service specialized in multi-user web communication. The Photon Engine[8] provides a range of tools for Unity developers to transform their projects into multi-user consolidated projects. This project utilizes Photon Unity Network (PUN) to resolve the communication among several connected system instances.

For this, PUN provides a UDP/HTTP technology that pursues change throughout several users. Each object receives a personal listener to communicate with the server. When a change occurs in a property that has been listening, the web service informs all the connected objects that the changes occur.

We implemented some techniques to recreate a multi-user server. First, we built the VR environment on demand. In other words, the environment constructs each object the moment it connects to PUN, which assigns a unique ID to each object upon creation. The system instantiates the same object for each VR instance initialized and connected, ensuring all users experience the same environment. We will now delve into the implemented components.

Each object created by PUN receives a listener to its position. When a user interacts with an object, it triggers the PUN network to inform all the other objects with the same ID that the position has changed. The exact process occurs with each property. For instance, if a button used to light a lamp is pressed by a user, the lamp will be lit for all users, not only for the player who did the action. Therefore, all the users share the same space and experiences in these spaces.

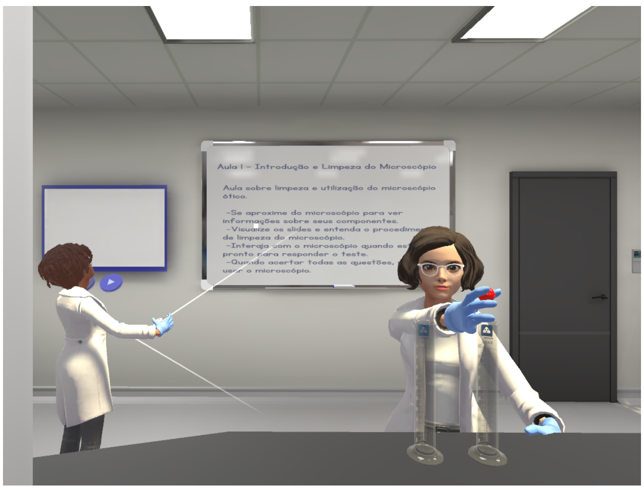

Figure 9. Multiple users loading into the same scene, each utilizing their own avatars.

[8]https://www.photonengine.com/

4.2 Avatar Server

Using the technology provided by PUN to diffuse object's updates through the systems. An avatar system was designed to make it possible for VR users to have their motion and positions replied to in the virtual space.

First, we create seven avatars in the ReadyPlayerMe (RPM)[9] platform, with different genders, bodies, hair, and personal details, to make it possible for users to choose the ones that most represent themselves. Figure 9 shows some of these avatars created in the scene developed. The RPM designed these avatars to make them movable once added to the object and skeleton. It is a technique that divides the rendered objects into multiple points connected. When the developer needs to move a part of the object, its right arm, for example, it can do it by changing the position of its elbow, the hand, or the finger since all parts are connected, and a change in one part drive the connected part into a new position that makes sense it still is connected.

This property allows avatars to receive animations, prebuild customizations of their bones' positions, and online movements using PUN. We design a pattern to make it possible to replicate each user's movement into his avatar.

- Once captured by the Virtual Reality platform, the position and rotation of the user's hands and head should be stored in a newly created object called 'Mirror,' whose properties are streamed by PUN.
- PUN instantiates as a usual object the user chooses as the avatar.
- The bone referenced by the avatar's hands and head updates its position and rotation based on the mirror's property that casts controllers' positions and rotation.
- The mirror object's property updates each time the user moves the controllers.

4.3 Audio Sources

We integrate Photon systems and inherit Avatar's Network ID to calculate the user's spatial position in the scene and create a 3D stereo sound.

To create this feature, we add an Audio Source on the Avatar object and set its ID on the Sound System. When the user's microphone recognizes that the user starts to talk, it triggers the audio source of the respective avatar to start playing the cast. We set the audio source so that it can only be heard within a 2m radius of the source and increases in intensity as the listener approaches it.

This approach increases the user's perception of reality and makes it possible to recreate more senses, guaranteeing an improvement in the feeling of co-presence.

5 Case-Study

To drive our development, the multi-disciplinary team, composed of academics from life and computational sciences, weaves a case for this system, defining requirements for a lesson in a lab and evaluating the results, endorsing the require-

[9]https://readyplayer.me/pt-BR

ments' achievement. This section describes the case study and the development of our first proof of concept.

The first step in the project's development was to understand and identify the first set of needs of the users involved in the problem that must be solved. List of the needs:

- The user should select a class to take in the lab.
- There must be a way of connecting multiple users in the same scene.
- Users must be able to interact with the lab using their hands.
- User must be able to move around the scene.
- There must be a way for the user to watch a video in two dimensions on a screen in the lab.
- There must be a way for the user to watch a 3D video on a screen in the lab.
- There must be a way for the user to view and scroll through items from a slide on a screen in the lab.
- There must be a way for the user to answer tests in the lab.
- User must be able to hold specific objects within the lab and move their angle or position freely.
- User usage information must be registered in some teaching data storage system so that responsible teachers can view it.
- The laboratory must model based on actual laboratories, creating the feeling of being there.
- Item and environment realism is essential based on real labs, but color contrast is required to ensure items' readability in a virtual reality environment.
- The game should run at a frame rate over than 60 on computers with average hardware. This aspect ensures greater comfort and less chance of motion sickness or other joint complications when using virtual reality glasses.
- Hand interactions should be limited to pressing virtual buttons or, at most, one physical button, thus ensuring future compatibility with other low-cost hand-tracking methods.
- User must be able to move using an analog stick on the controller or teleportation. Offering multiple options, users can select the one that best fits their use style and causes less initial discomfort.

After listing the requirements for carrying out this case, the next step in creating the laboratory was to look for references. Seeking to create a realistic environment, the dominant colors and construction characteristics, such as the material used and piping, electronic equipment, work benches, and exposed items, among others, were observed in the images found.

After we enumerate these items, we search for objects already modeled for free use on the internet. Some of these objects are representations of chemical experiments. Others represent storage flasks and a microscope. In addition to the items directly related to the Biological Sciences area, others, such as books and the fire extinguisher, were also selected to compose the laboratory scenario.

We modeled the objects not found using Blender[10], free and open-source software for 3D modeling and animation. Some of these objects are the laboratory bench and an air conditioner.

We counted and normalized the number of polygons in each object to enhance the performance of lower-power systems, as shown in Figure 10. This approach ensures that freely available items from the internet do not have excessive polygons, which could otherwise strain the hardware and compromise the user experience.

Optimization is one of the significant factors to consider when designing virtual reality. Many polygons place a massive load on graphics cards, causing performance to drop. To avoid possible discomfort that the user may experience, ensuring that the software runs at a high frame rate is essential.

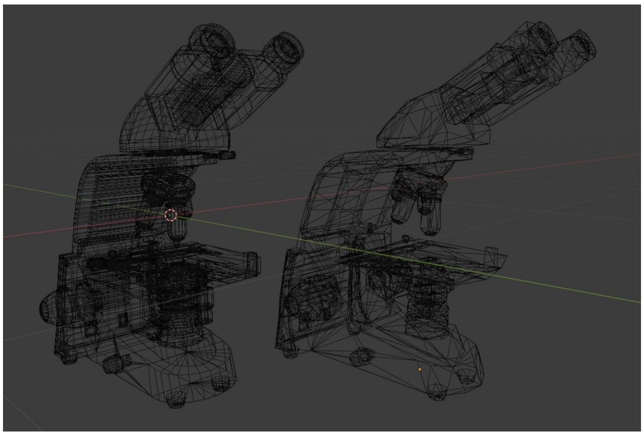

Figure 10. Left microscopy with the original mesh. Right microscopy with mesh reduced.

We imported the models into *Unity* and correctly built the lab. We considered the characteristics extracted from the reference images, such as colors and dimensions, and created a three-dimensional environment to portray the same experience in a real-world laboratory. Figure 11 is the polygonal model with the applied textures without any light and shading treatment.

Figure 11. Final Lab before light and shadows treatment.

The last step is the lighting part with the lab fully modeled and built within *Unity*. For virtual reality, real-time lighting is highly costly. We used pre-calculated lighting and burned it fixedly in the image, aiming for performance, especially on weaker hardware. The lights do not affect the real-time environment in which the player is. However, this technique helps to give realism to the environment, which until then seemed two-dimensional due to the lack of lighting.

[10]https://www.blender.org/

We changed the scene outside the laboratory to have different levels of detail according to the distance of each element about the player seeking to optimize the game further using a technique called LOD, *level of detail*. Distant elements have a lower level of detail, while closer components have a higher level of detail. In addition to the LOD, we also applied an *occlusion culling* technique, which prevents objects not in the player's field of view from being rendered by the camera. Figure 12 shows the result.

Figure 12. Final Lab after light and shadows treatment.

With the conclusion of the environment, now is time to include the components described in Section 3.4. The components contain the scripts to access our developed LMS API and show the data configured by the educators. For this work, we included a Slider Component (Figure 3), a Video Component (Figure 4), a Quiz Component (Figure 5), and a Whiteboard (Figure 6).

Finally, the VR interface was included to complete the scenario. We chose the Steam VR[11] plugin to provide interaction with users. It is compatible with the Meta Quest and HTC VIVE, where users can interact with virtual hands. Both devices were available for the development of this project. Although the system captures the user's moves through the gadget interfaces, they can also use the teleport feature to move in the scene.

The team successfully integrated all the modules in this case study to enhance the learning experience. The teacher effectively incorporated data into the Virtual Reality (VR) platform by leveraging the Learning Management System (LMS) platform.This integration enabled the programming team to customize the environment. Students could actively engage with the VR environment by incorporating videos, slides, and quizzes while the system assessed them. Notably, we recorded all student interactions in the database for further retrieval through the developed xAPI interface. Furthermore, we carefully analyzed the gathered data, resulting in the automated generation of graphs and tables that the teacher can use for activity development and planning. These valuable insights also help researchers in their analysis of student behavior in the virtual reality setting, eliminating the need for constant monitoring of student activity.

[11] https://assetstore.unity.com/packages/tools/integration/steamvr-plugin-32647

5.1 Multiuser integration

The multiuser integrations required adaptations in previous work. We created a loading scene where the student chose their avatar for loading in the main scene.

Once chosen, the user gets transported to the lab, and the other features are activated. The users then can interact with each other by gesture and voice. They receive haptic feedback when touching scene objects or by touching each other hands.

Through Learning Analytics systems, we record only the interactions with objects chosen by teachers, as there are countless ways to communicate. For example, a hand gesture might signal the need to lower an object or speak more slowly, developing each group's interaction style. By focusing on object interactions, we ensure that the recorded material is organized for evaluation.

6 Heuristic Evaluation

In this chapter, we will present the heuristic evaluation of the EduVR platform, following the heuristic proposed by Guo *et al*. [2024]. Section 6.1 briefly explains the heuristic evaluation system, Section 6.2 we will present the evaluation methodology, and finally, Section 6.3 brings the results found.

6.1 Heurist for Virtual Reality evaluation

The heuristics proposed by Guo (2024) cover nine areas of usability design evaluation for virtual reality. Each heuristic addresses a crucial aspect to observe during the evaluation, as presented in Table 1.

Each evaluation aims to identify aspects that can interfere with human interaction and assess the severity of these interferences according to the scale recommended by Nielsen (1992): 0 - "Not a usability problem," 1 - "Superficial problem," 2 - "Minor problem," 3 - "Major problem," and 4 - "Usability disaster."

The issues identified within the same heuristic are aggregated, and the mean severity of these issues represents the heuristic's score.

The team considered heuristic scores below 2 points to indicate promising results.

6.2 Heuristics Application

Two experts evaluated EduVR's design: one specializing in information technology with extensive knowledge in virtual reality and interface design and the other specializing in education and healthcare. Both are authors and stakeholders who do not participate in the system's development.

Each evaluation session consisted of three steps and lasted approximately one hour. The first step involved presenting the heuristics, listed in Table 1, and explaining the intent of evaluating the system. The researcher described each heuristic in detail, including how and why asses them. The specialist experimented with the application in the second step and reported the identified issues.

	Heuristic	Explanation
1	Visibility of system status	The system must clearly indicate to the users which objects of the they can interact with and the ones they cannot. It also should always keep users informed about what is going on through appropriate feedback within a reasonable amount of time.
2	Natural engagement	Interaction should approach the user's expectation of interaction in the real world as far as possible. Interpreting this heuristic will depend on the naturalness requirement and the user's sense of presence and engagement.
3	Error prevention	Carefully prevent problems from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action
4	Consistency and standards	The VR environment should be consistent in all aspects. Users should not have to wonder whether different words, situations, or actions mean the same thing
5	Realisticfeedback	The effect of the user's actions on virtual world objects should be immediately visible and conform to the laws of physics and the user's perceptual expectations
6	Navigation and orientation support	The users should always be able to find where they are in the VR environment and return to known, reset positions. These have to be judged in a trade-off with naturalness
7	Low memory load	Minimize the demands on the user's memory in the VR environment by making the objects, options, and actions are visible and easily accessible
8	Mental comfort	The system should be designed to prevent sensations of physical illness during use by preventing jarring movement lag, increasing realism of visuals, and so on
9	Recovery from errors	Virtual-reality experiences often contain a high volume of interactions, some of which are complicated or unfamiliar to users. A VR system should provide the user with the approaches to recover from system errors or any undesired situation when the user cannot recover by himself.

Table 1. VR Heuristics explanation. Adapted from Guo *et al.* [2024] .

Reported Issue	Mean Severity	Related Heurist
The system may fails when interacting with some objects.	1,5	1
Some graphical elements are not in 3D.	0,5	1
Moving with an object in hand creates difficulties for the user.	1	2
Larger objects allow the user to surpass the physical barrier.	0,5	3
The system does not allow interaction with all objects.	0,5	5
The countertops did not provide tactile feedback.	0,5	5
Responsiveness is lost during fast movements.	1	5
Movement can be difficult to learn.	3	6
The screen glitches when changing scenes.	0,5	8
Headset wires can interfere the task	1	8
Some objects show aliasing.	0,5	8

Table 2. Usability Issues List.

In the third step, at the end of the experiment, we conducted a semi-structured interview with the participants. We reviewed the issues reported during the system's experimentation and asked the participants to evaluate the severity of each issue on a scale from 0 to 4, following the guidelines proposed by Guo *et al*. [2024]. After that, we reread the heuristics to uncover any unreported issues and asked again to report if it was the case.

After the sessions, we classified the issues according to the heuristics. Table2 summarizes the results.

6.3 Results

The experts' evaluation indicated that the system had few flaws, with an average heuristic score of 1.17 on the severity scale. The most significant problems were found in the heuristics of Navigation and Orientation Support, averaging a severity of 3 points, and Visibility of System Status, averaging 1.5 points. There are no identified issues in Consistency and Standards, Low Memory Load, and Recovery from Errors (Heuristics 4, 7, and 9).

Table 2 presents the issue identified in the experts' evaluation with the mean severity of each highlighted struggle.

Unfortunately, the team was not surprised by the high score on Heuristic 3.Virtual reality movement can cause sickness and nausea in most users [Howard and Van Zandt, 2021]. Reducing these effects limits users to moving in the ambiance through teleports, which is not a habitual way of mobility and requires more adapting compared to other possibilities. Section 7 discusses these and other challenges in creating virtual reality multiusers and how the team managed to resolve and reduce the severity score of the heuristics.

7 Lessons Learned on Constructing Multi-user Virtual Reality System.

Constructing multiplayer scenes requires both stable internet connectivity and a responsive server. There is a paradox in crafting these scenes: To ensure efficiency, developers must minimize the load of information transmitted across all devices. At the same time, developers need to increase the volume of information to ensure smooth visualization. Achieving the perfect balance between these requirements was not a simple task.

7.1 Smooth movements

Humans perceive smooth movements when the screen's framerate goes beyond 30 frames per second (fps), but it gets better the more this number goes [Zanker and Harris, 2002]. Users manipulating objects in a multi-user environment receive an overall framerate of 60fps, considered an adequate framerate. However, the multi-user server does not send the same fps to the objects it controls.

This change happens because the objects are instantiated locally in each application. If users do not manipulate the objects, the framerate will remain the same as the application, but when it does, the lack of communication between the systems causes lag for users.

7.2 Updating positions

To understand why this occurs, it's important to elucidate how a position updates in Virtual reality. Each object in Virtual Reality receives a position in the scene represented by a vector of their x,y, and z positions. When the multi-user server sends an order to change the objects' positions, the application creates a leap from the original position to the new one. If only one change exists, the leap will appear smooth, with an adequate framerate. However, if multiple position changes, the application will try to create smooth movement among every position, the application will destroy the balance of fps.

7.3 Two solutions

The team devised two solutions to address this issue. The first solution updates positions rapidly, preventing the user from perceiving any discontinuities resulting from the application's leaps. Alternatively, the second solution slows down the process, allowing the application sufficient time to fix these leaps, thereby ensuring smooth motion.

The first option, in general, provides a better perception of smoothness, but it requires lots of data transmitted. The team uses a frequency of one update every 0.1 seconds to ensure a lack of lag for the user. This logic requires much stability from the network, making the system more fragile to external interferences.

The second option uses an update each second, which is slow and requires much less data. It is great to present changes between two users if these changes do not interfere with each other's tasks. This option benefits the avatar's representation since its representations do not affect the owner's usability or the other's perception.

For the other objects, the second option was ineffective. The slower update makes the object appear to fly around the scene for the user that it is not directly controlling it. Thus, the team had to use the first option.

The team felt vertigo each time that the smoothness was not adjusted. All the adaptations of this work presented in this section help to enlighten the problem for future production and provide some direction on handling the problem.

8 Lessons Learned on Constructing Virtual Reality Educational Environments

This section discusses the lessons learned and challenges encountered during the development of educational virtual reality educational environments.

- **How do captivate tutors to become part of the team:** The first challenge in creating a platform that changes the common way of teaching is to involve professors. Since integrating new systems into traditional education has been a natural challenge, making professors believe that it is possible to evolve their way of teaching is not simple. The first lesson learned is that all professors want to integrate technology but must learn how. However, the experience of trying virtual reality changes how they imagine how to integrate. The use of Rich Media is a powerful tool to transform their mind.
- **How to create a friendly interface allowing educators to create their 3D lessons:** After starting the development, we noticed that creating a simple assignment for a professor unfamiliar with programming can become a real problem. It introduced an interface that looks simple enough for the educator to make the process personalized. The interface needed to be familiar and intuitive for the user. That is why the team established the development of Learning Press. Uploading multimedia or creating a quiz is a daily task for web educators.
- **How to incorporate changes from the interface in the proposal task:** After creating the interface, the main challenge was integrating multimedia. Changing multimedia in the development project phase is easy, but doing so after the program has been executable is quite challenging. Creating components that receive their content at the building does not require reprogramming. We proposed a simple way to integrate changes by incorporating changeable environmental components. Alongside this, the team prepared the ambiance to provide all the tools needed to achieve the goals proposed for the tutors. In a laboratory, e.g., the students can be given a proposal to look at the microscopy. A component that shows the task and object microscopy was needed. Otherwise, object microscopy does not need to be replaced if given a task to analyze a periodic ta-

ble. The lecturer must only change the assignment and include a second object: the Periodic Table.

- **How to evaluate students based on their choices:** The first criterion when imagining how to evaluate students is the idea of right and wrong. The simple idea of using multiple options or evaluating based on some text is conventional. However, virtual reality should not have only one way to archive a goal. Various possibilities of choice are precisely the great trump of using VR. So, to look for alternatives, abandoning the idea of the duplicity of correctness and creating the idea of developing a way of knowing where the best way to do something is based on a profile, prebuild, based on the experience of students with the same profile that the user. The idea of using distractors came to synthetics the evaluation system.
- **How to release a friendly LMS interface for educators to connect different 3D interfaces:** The team developed a laboratory-focused 3D environment for cytology and integrated the proof of concept with an LMS interface. Customization development was required to complete this action. However, it must plan efficient interaction mechanisms when the number of three-dimensional environments offered to educators increases. The system must recognize which components are available for student data collection or even allow educators to choose these components. In this context, the challenge is to allow the customization of the spatial arrangement of the 3D elements of the application. At the same time, the class is being assembled in the context of the LMS.
- **Ethical Issues:** Although data collection can benefit the student, ethical and privacy aspects must be preserved. Recording a student's day-to-day activities must comply with local laws such as *General Data Protection Regulation* (GDPR) at the European level and the *Lei Geral de Proteção de Dados* (LGPD) in the Brazilian context. An erroneous exposure of data can generate side effects such as demotivating. It is important to emphasize that behavioral data can shape social influences like social networks. These same data can be used as a basis for scientific research. Ethics and legislation must accompany the professionals' routine in all these scenarios.

9 Conclusions and Final Discussions

EduVR development provides teachers with access to various pedagogical and technological tools in Virtual Reality in a dynamic and well-structured manner. Based on the pedagogical approach of active learning, which believes that students can leverage their development with new technologies, We created the environment to allow students to fully benefit from the power of immersion provided by Virtual Reality. To achieve this, we created a detailed environment so that the activities closely resemble real-life situations.

For teachers, the developed systems enhance their control of the environment. Teachers can customize the environment through the LMS platform with their didactic material, such as slides, videos, and questions. Additionally, teachers can get feedback on individual and collective student interaction with the proposed activities by integrating Learning Analytics tools.

To complement this entire educational system, we integrated a multi-user system, where more than one person coexists in the same environment. Teachers can directly guide a student or multiple students to perform activities together, broadening the ways of thinking about studying in virtual reality and creating a virtual classroom that feels more real. In this environment, people see and interact with each other, fostering new forms of presence that can change how students learn. Future work aims to investigate these effects and their consequences.

Finally, we conducted a heuristic evaluation of the developed system, and we found the results to be positive, with few points of severity in the applied heuristic. We propose, as future research, the creation of a new heuristic for multiuser virtual reality, as we have not found any in the literature so far.

Declarations

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Authors' Contributions

Arilton, Iago, Koda, and André are undergraduate students who work in programming, software development, designing computer programs, implementing computer code and supporting algorithms, and testing existing code components. Robson, Paula, and Mateus are graduate students who worked on the project research, providing ideas and formulation for the evolution of overarching research goals and aims. Robson also worked on multiplayer software development. Claudia is a senior researcher in the pharmacy field and serves as a stakeholder. She also validates the proposed solution. Saul is responsible for acquiring the financial support for the project leading to this publication. He has oversight and leadership responsibility for research planning and execution, including external mentorship. All authors contributed to preparing, creating, and presenting the published work, including writing the initial draft.

Competing interests

The authors declare they have no competing interests.

Availability of data and materials

EduVR materials and packages are readily accessible to the community via the GitHub repository: https://github.com/xr4good/EduVr.

References

Armbruster, P., Patel, M., Johnson, E., and Weiss, M. (2009). Active learning and student-centered pedagogy improve student attitudes and performance in introductory biology. *CBE—Life Sciences Education*, 8(3):203–213. DOI: https://doi.org/10.1187/cbe.09-03-0025.

Back, T., Tinga, A., Nguyen, P., and Louwerse, M. (2020). Benefits of immersive collaborative learning in cave-based virtual reality. 17. DOI: https://doi.org/10.1186/s41239-020-00228-9.

Bakkes, S., Tan, C. T., and Pisan, Y. (2012). Personalised gaming: a motivation and overview of literature. In *Proceedings of the 8th Australasian Conference on Interactive Entertainment: Playing the System*, pages 1–10. DOI: https://doi.org/10.1145/2336727.2336731.

Brown, C., Bhutra, G., Suhail, M., Xu, Q., and Ragan, E. D. (2017). Coordinating attention and cooperation in multi-user virtual reality narratives. In *2017 IEEE Virtual Reality (VR)*, pages 377–378. IEEE.

Clow, D. (2013). An overview of learning analytics. *Teaching in Higher Education*, 18(6):683–695.

Cooper, A. (2014). Learning analytics interoperability-the big picture in brief. *Learning Analytics Community Exchange*.

Crisol-Moya, E., Romero-López, M. A., and Caurcel-Cara, M. J. (2020). Active methodologies in higher education: perception and opinion as evaluated by professors and their students in the teaching-learning process. *Frontiers in Psychology*, 11:1703.

Dichev, C. and Dicheva, D. (2017). Gamifying education: what is known, what is believed and what remains uncertain: a critical review. *International journal of educational technology in higher education*, 14(1):1–36.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., and Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the national academy of sciences*, 111(23):8410–8415.

Freitas, S., Rebolledo-Mendez, G., Liarokapis, F., Magoulas, G., and Poulovassilis, A. (2010). Learning as immersive experiences: Using the four-dimensional framework for designing and evaluating immersive learning experiences in a virtual world. *British Journal of Educational Technology*, 41:69–85. DOI: https://doi.org/10.1111/j.1467-8535.2009.01024.x.

Gierl, M. J., Bulut, O., Guo, Q., and Zhang, X. (2017). Developing, analyzing, and using distractors for multiple-choice tests in education: A comprehensive review. *Review of Educational Research*, 87(6):1082–1116.

Gorisse, G., Christmann, O., Amato, E. A., and Richir, S. (2017). First-and third-person perspectives in immersive virtual environments: presence and performance analysis of embodied users. *Frontiers in Robotics and AI*, 4:33. DOI: https://doi.org/10.3389/frobt.2017.00033.

Guo, X., Kumar Nerella, K., Dong, J., Qian, Z., and Chen, Y. (2024). Understanding pitfalls and opportunities of applying heuristic evaluation methods to vr training systems: An empirical study. *International Journal of Human–Computer Interaction*, 40(9):2168–2184. DOI: https://doi.org/10.1080/10447318.2022.2161238.

Howard, M. C. and Van Zandt, E. C. (2021). A meta-analysis of the virtual reality problem: Unequal effects of virtual reality sickness across individual differences. *Virtual Reality*, 25(4):1221–1246. DOI: https://doi.org/10.1007/s10055-021-00524-3.

Jerald, J., LaViola Jr, J. J., and Marks, R. (2017). Vr interactions. In *ACM SIGGRAPH 2017 Courses*, pages 1–105. DOI: https://doi.org/10.1145/3084873.3084900.

Johansson, M. and Roupé, M. (2022). Vr in construction–multi-user and multi-purpose. In *Proceedings of the 22nd International Conference on Construction Applications of Virtual Reality(CONVR 2022)*, volume 22, pages 248–259.

Jung, S., Wu, Y., McKee, R., and Lindeman, R. W. (2022). All shook up: The impact of floor vibration in symmetric and asymmetric immersive multi-user vr gaming experiences. In *2022 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pages 737–745. IEEE. DOI: https://doi.org/10.1109/VR51125.2022.00095.

Khaldi, A., Bouzidi, R., and Nader, F. (2023). Gamification of e-learning in higher education: a systematic literature review. *Smart Learning Environments*, 10(1):10.

Kim, H., Nah, S., Oh, J., and Ryu, H. (2019). Vr-moocs: A learning management system for vr education. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pages 1325–1326. IEEE. DOI: https://doi.org/10.1109/VR.2019.8798106.

Kirkwood, A. and Price, L. (2014). Technology-enhanced learning and teaching in higher education: what is 'enhanced'and how do we know? a critical literature review. *Learning, media and technology*, 39(1):6–36.

Kitson, A., Prpa, M., and Riecke, B. E. (2018). Immersive interactive technologies for positive change: a scoping review and design considerations. *Frontiers in psychology*, 9:1354.

Kuznetcova, I., Lin, T.-J., and Glassman, M. (2021). Teacher presence in a different light: Authority shift in multi-user virtual environments. *Technology, Knowledge and Learning*, 26:79–103. DOI: https://doi.org/10.1007/s10758-020-09438-6.

Laal, M. and Laal, M. (2012). Collaborative learning: what is it? *Procedia - Social and Behavioral Sciences*, 31:491–495. World Conference on Learning, Teaching Administration - 2011. DOI: https://doi.org/10.1016/j.sbspro.2011.12.092.

Lang, C., Siemens, G., Wise, A., and Gasevic, D. (2017). *Handbook of learning analytics*. SOLAR, Society for Learning Analytics and Research New York.

Laurillard, D. (2007). Modelling benefits-oriented costs for technology enhanced learning. *Higher Education*, 54(1):21–39.

Lim, K. C. (2015). Case studies of xapi applications to e-learning. In *The twelfth international conference on eLearning for knowledge-based society*, pages 3–1.

Ludvigsen, S. and Mørch, A. (2010). Computer-supported collaborative learning: Basic concepts, multiple perspectives, and emerging trends. *The international encyclopedia of education*, 5:290–296.

Mangaroska, K. and Giannakos, M. (2018). Learning analytics for learning design: A systematic literature review of analytics-driven design to enhance learning. *IEEE Transactions on Learning Technologies*, 12(4):516–534.

Monk, A., Davenport, L., Haber, J., and Wright, P. (1993). *Improving your human-computer interface: A practical technique*. Prentice-Hall New York.

Murtza, R., Monroe, S., and Youmans, R. J. (2017). Heuristic evaluation for virtual reality systems. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 61, pages 2067–2071. SAGE Publications Sage CA: Los Angeles, CA. DOI: https://doi.org/10.1177/1541931213602000.

Nielsen, J. (1992). Finding usability problems through heuristic evaluation. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 373–380. DOI: https://doi.org/10.1145/142750.142834.

Pakanen, M., Alavesa, P., Van Berkel, N., Koskela, T., and Ojala, T. (2022). "nice to see you virtually": Thoughtful design and evaluation of virtual avatar of the other user in ar and vr based telexistence systems. *Entertainment Computing*, 40:100457. DOI: https://doi.org/10.1016/j.entcom.2021.100457.

Pan, Z., Cheok, A. D., Yang, H., Zhu, J., and Shi, J. (2006). Virtual reality and mixed reality for virtual learning environments. *Computers & graphics*, 30(1):20–28.

Pane, J. F., Steiner, E. D., Baird, M. D., and Hamilton, L. S. (2015). *Continued Progress: Promising Evidence on Personalized Learning*. RAND Corporation, Santa Monica, CA. DOI: https://doi.org/10.7249/RR1365.

Pathania, M., Mantri, A., Kaur, D. P., Singh, C. P., and Sharma, B. (2021). A chronological literature review of different augmented reality approaches in education. *Technology, Knowledge and Learning*, pages 1–18.

Paulsen, L., Dau, S., and Davidsen, J. (2024). Designing for collaborative learning in immersive virtual reality: a systematic literature review. *Virtual Reality*, 28(1):63. DOI: https://doi.org/10.1007/s10055-024-00975-4.

Philippe, S., Souchet, A. D., Lameras, P., Petridis, P., Caporal, J., Coldeboeuf, G., and Duzan, H. (2020). Multimodal teaching, learning and training in virtual reality: a review and case study. *Virtual Reality & Intelligent Hardware*, 2(5):421–442.

Säljö, R. (1979). Learning about learning. *Higher education*, 8(4):443–451.

Schild, J., Flock, L., Martens, P., Roth, B., Schünemann, N., Heller, E., and Misztal, S. (2019). Epicsave lifesaving decisions–a collaborative vr training game sketch for paramedics. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pages 1389–1389. IEEE. DOI: https://doi.org/10.1109/VR.2019.8798365.

Schild, J., Misztal, S., Roth, B., Flock, L., Luiz, T., Lerner, D., Herkersdorf, M., Weaner, K., Neuberaer, M., Franke, A., *et al*. (2018). Applying multi-user virtual reality to collaborative medical training. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pages 775–776. IEEE. DOI: https://doi.org/10.1109/VR.2018.8446160.

Schroeder, R. (2001). *The social life of avatars: Presence and interaction in shared virtual environments*. Springer Science & Business Media.

Schultze, U. (2010). Embodiment and presence in virtual worlds: a review. *Journal of Information Technology*, 25(4):434–449. DOI: https://doi.org/10.1057/jit.2009.25.

Secretan, J., Wild, F., and Guest, W. (2019). Learning analytics in augmented reality: Blueprint for an ar/xapi framework. In *2019 IEEE International Conference on Engineering, Technology and Education (TALE)*, pages 1–6. IEEE.

Spittle, B., Frutos-Pascual, M., Creed, C., and Williams, I. (2022). A review of interaction techniques for immersive environments. *IEEE Transactions on Visualization and Computer Graphics*.

Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. journal of communication, 42 (4), 73-93. *Future Generation Computer Systems*, 94:302–316.

Sutcliffe, A. and Gault, B. (2004). Heuristic evaluation of virtual reality applications. *Interacting with computers*, 16(4):831–849. DOI: https://doi.org/10.1016/j.intcom.2004.05.001.

Tanaka, E. H., de Almeida, L., de Freitas Gouveia, G. S., Clerici, R. P. S., Alves, A. H. F., and de Oliveira, R. R. (2023). A collaborative, immersive, virtual reality environment for training electricians. *Journal on Interactive Systems*, 14(1):59–71. DOI: https://doi.org/10.5753/jis.2023.2685.

Tuparov, G., Keremedchiev, D., Tuparova, D., and Stoyanova, M. (2018). Gamification and educational computer games in open source learning management systems as a part of assessment. In *2018 17th International Conference on Information Technology Based Higher Education and Training (ITHET)*, pages 1–5. DOI: https://doi.org/10.1109/ITHET.2018.8424768.

Viol, R. S., Fernandes, P. C., Lacerda, I. I., Melo, K. G. F., Nunes, A. J. D. A., Pimenta, A. S. G. a. M., Carneiro, C. M., Silva, M. C., and Delabrida, S. (2023). Eduvr: Towards an evaluation platform for user interactions in personalized virtual reality learning environments. In *Proceedings of the XXII Brazilian Symposium on Human Factors in Computing Systems*, IHC '23, New York, NY, USA. Association for Computing Machinery. DOI: https://doi.org/10.1145/3638067.3638131.

Wang, C. and Huang, L. (2021). A systematic review of serious games for collaborative learning: Theoretical framework, game mechanic and efficiency assessment. *International Journal of Emerging Technologies in Learning (iJET)*, 16:88. DOI: https://doi.org/10.3991/ijet.v16i06.18495.

Wharton, C., Rieman, J., Lewis, C., and Polson, P. (1994). The cognitive walkthrough method: A practitioner's guide. In *Usability inspection methods*, pages 105–140. DOI:

https://doi.org/10.5555/189200.189214.

Wienrich, C., Schindler, K., Döllinqer, N., Kock, S., and Traupe, O. (2018). Social presence and cooperation in large-scale multi-user virtual reality-the relevance of social interdependence for location-based environments. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pages 207–214. IEEE. DOI: https://doi.org/10.1109/VR.2018.8446575.

Zanker, J. and Harris, J. (2002). On temporal hyperacuity in the human visual system. *Vision Research*, 42(22):2499–2508. DOI: https://doi.org/10.1016/S0042-6989(02)00301-2.

Zheng, L., Xie, T., and Liu, G. (2018). Affordances of virtual reality for collaborative learning. In *2018 International Joint Conference on Information, Media and Engineering (ICIME)*, pages 6–10. DOI: https://doi.org/10.1109/ICIME.2018.00011.

Ángel Serrano-Laguna, Martínez-Ortiz, I., Haag, J., Regan, D., Johnson, A., and Fernández-Manjón, B. (2017). Applying standards to systematize learning analytics in serious games. *Computer Standards & Interfaces*, 50:116–123. DOI: https://doi.org/10.1016/j.csi.2016.09.014.