Interactive Development of a Virtual Reality System for Training and Evaluation in Electric Vehicle Technology

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ABSTRACT
The global transition to electric mobility necessitates a fundamental recalibration of professional skills in the automotive sector. The complexity of high-voltage systems, battery packs, and software diagnostics in electric vehicles (EVs) creates a significant skills gap for technicians. Traditional training methods, which involve costly physical prototypes and inherent safety risks, are becoming increasingly inefficient. This paper proposes the development of a software system, called VRQUIZ, based on virtual reality (VR) designed to facilitate a complete training and evaluation cycle, from the creation of interactive training modules to the practical simulation of diagnostics and repairs, and finally, to performance evaluation. The system consists of an intuitive desktop application for professors, an immersive VR application for students, and a centralized server. The paper analyzes experimental solutions of user interaction techniques in a virtual reality system for training and assessing knowledge in electric vehicle technologies.

Author Keywords
Electric Vehicles, Virtual Reality, User Interaction Techniques, Training Lessons.

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INTRODUCTION
The automotive industry is progressing, with a rapid shift from internal combustion engines to electric vehicles (EVs). This change is not just a technological one but also a transformation of the skill requirements for technicians and engineers in the field. The maintenance, diagnostics, and repair of an EV involve handling high-voltage systems, lithium-ion batteries, and complex software networks - areas where safety risks are significant, and complexity often exceeds the knowledge gained through traditional methods. Physical prototypes and testing equipment are extremely costly, and simulating faults in a safe manner is difficult and risky.

This traditional model struggles to capture student attention and foster deep understanding, particularly for complex or abstract concepts. The VRQUIZ system addresses this gap by proposing an innovative solution centered on Virtual Reality (VR). It offers an immersive and interactive environment where abstract ideas can be visualized as tangible 3D models, allowing professors to present objects that are either too large, too small, or physically inaccessible in a conventional classroom setting. This immersive experience is designed to significantly boost student engagement and comprehension.

By creating a digital training environment, VR eliminates physical risks and the costs associated with expensive equipment. The students can repeatedly practice work procedures, diagnose virtual faults, and learn critical safety protocols without being exposed to real-world dangers.

The present research and pilot project address this urgent market need by developing an integrated software system that covers the entire professional training cycle. The main objective of the research is to create a dedicated VR system for the training and evaluation of technicians in the electric automotive field (Fig. 1). To achieve this goal, the following specific objectives were defined:

- Develop an intuitive **desktop application for instructors and professors**: This will allow for the quick creation and configuration of lessons and tests, without requiring programming knowledge, and will ensure data persistence on a central server (Fig. 2). An authoring interface allows for the creation of training modules, fault simulations, and the configuration of diagnostic tests, using 3D models of electric vehicles.

Figure 1. VRQUIZ system develop interactive lessons and education materials within the virtual 3D space.

- Develop a **virtual reality application for trainees and students**: An immersive interface that allows technicians to go through the lessons prepared by instructors and take tests to assess their new knowledge in a VR environment. The immersive environment supports the trainees to practice maintenance and diagnostics procedures, using interactive virtual tools and simulating work scenarios.
- Develop a **centralized server**: It is an essential component for managing training resources such as lessons and users, processing data on learner performance, and generating detailed assessment reports.
- Ensure a complete **functional flow**: From the creation of a diagnostic scenario to the final evaluation of a trainee's skills, the entire process must be seamless and efficient.

The main challenge of the research is to design and experiment with interactive techniques for creating a lesson. Both presentations and questions are created interactively. It also specifies the way to score answers and calculate the overall grade of a lesson. Solutions are explored for defining and verifying the execution of tasks or scenarios in the 3D virtual space. What are the simplest and most effective interactive techniques for creating and executing a lesson? What are the advantages and disadvantages of these interactive techniques?

RELATED WORKS

The use of virtual reality in the automotive sector is not a new concept. Companies such as Ford, BMW, and Volkswagen have been using VR for years for design reviews, manufacturing process simulations, and even driver training (e.g., driving simulation systems). However, most of these applications are oriented towards pre-production or marketing stages and do not specifically address the challenges related to the technical maintenance of vehicles.

In the specific context of electric vehicles (EVs), the challenges are particularly important. Diagnostic errors can lead to high repair costs, and incorrect handling procedures for high-voltage components can cause serious accidents. Traditional education relies on service manuals and physical training workshops, where access to prototypes and diagnostic equipment is limited and expensive.

There are a few isolated solutions that use VR for technical training, but they are often:

- *Platforms with fixed content*: "Turn-key" solutions that offer a limited set of predefined training scenarios (e.g., disassembling a specific engine).
- *Rudimentary evaluation systems*: These only track the completion of a task, not the correctness, efficiency, or adherence to safety protocols.

The system proposed in this paper is distinguished by two key aspects. First, it offers an *open and flexible framework for content and lesson creation*, allowing instructors to simulate any type of fault or repair procedure, from simple to complex. Second, it integrates a *lesson execution* that monitors every action of the trainee (tool selection, step order, adherence to safety protocols) to generate a detailed performance analysis and knowledge assessment. Our pilot project aligns with current trends in "simulation-based learning," which demonstrates that repeated practice in controlled environments significantly improves success rates and practical skills.

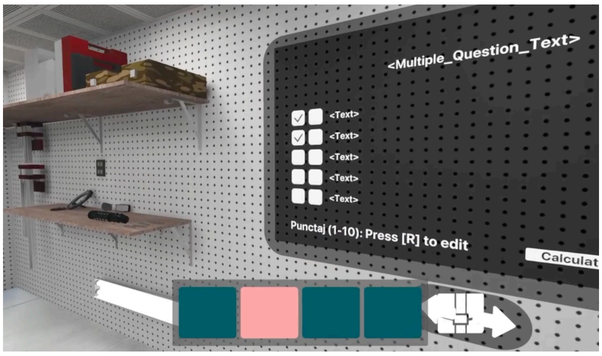

Figure 2. The lessons are created in the virtual 3D space and the questions are configured interactively onto the panel.

Muser et al. [1] highlight the VR's potential to facilitate simultaneous learning experiences for multiple students within a shared virtual space. An experimental study involving 14 educators, who completed VR tasks related to engineering design, revealed that these tasks required a medium level of cognitive effort. This finding is significant as it suggests VR can effectively stimulate critical thinking without inducing frustration or cognitive overload, thus promoting deeper engagement.

Koc et al. [2] discuss the Human-Computer Interaction (HCI) using Meta Quest 2 headsets, along with development tools such as Unity and 3D modeling software like Blender. The paper showcases interactions like opening car doors, accessing interior components, and changing vehicle colors.

Staretu [3], focuses on the transformative potential of VR in technical training disciplines, particularly in electrical and mechanical engineering. It identifies several key advantages that VR brings to vocational education: repeatability of complex procedures, simulation of student safety, minimize the need for expensive physical equipment, and enhance student motivation.

Kucera et al. [4] explores the development and integration of both Virtual Reality and Mixed Reality (MR) applications specifically tailored for mechatronics education. It emphasizes MR's unique advantage in overlaying virtual elements onto the real world, creating a hybrid environment. This capability offers particularly beneficial for presenting intricate mechatronic concepts, enabling students to visualize abstract functionalities in a real-world context,

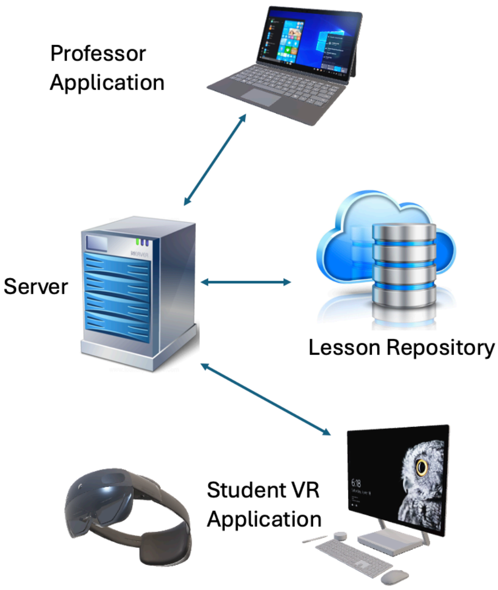

Figure 3. Conceptual system architecture.

which can significantly improve learning efficiency and retention.

Hernandez-Chavez et al. [5] critically analyzes the role of VR as an innovative educational tool, especially in promoting sustainability within engineering curricula, with relevance particularly pronounced during the recent pandemic.

Luo et al. [6] discuss the rapid growth in popularity and integration of virtual reality and augmented reality (AR) technologies, due to the trend of online learning.

There are also several projects and commercial solutions that have provided inspiration and benchmarks for current research, providing insights into best practices and potential functionalities:

The **3spin Learning** project [7], allows for creating VR scenes directly in a browser and synchronizing them with VR headsets. Its strength lies in the ability to edit virtual scenes, adding objects and interactions. It demonstrates the effectiveness of a server in synchronizing materials created by the teacher with what the student sees, facilitating remote collaboration.

EngageVR - Virtual Classroom Solution [8], similar to 3spin Learning, focuses on a complete virtual classroom solution. The project adds essential features like multiplayer support and sharing media objects (images, documents, presentations, web pages) directly from OneDrive. It's ideal for delivering prepared materials but doesn't offer tools for assessing student knowledge through a set of questions.

Sanlab Learning - Electric Vehicle Training Simulator [9], is a simulator dedicated to vocational education for electric vehicles. It stands out for its user testing capability, not necessarily through direct questions, but through a series of guided steps in predefined scenes. While it allows for difficulty adjustment, teacher flexibility is limited in fully configuring scenes and actions.

Figure 4. Presentation of a PDF document onto the panel.

Metaverse Learning UK - Electric Vehicle Program [10], is very similar to the Sanlab project, focusing on safety when working with electric vehicles, featuring predefined laboratories. The key difference is that it allows no user configuration, providing a strictly guided experience.

SYSTEM ARCHITECTURE

The system architecture is a distributed, client-server type, based on three main modules (Fig. 3):

1. ***Professor Application***: this is the primary interface for educators. Its core function is to empower professors to interactively create, configure, and manage virtual lessons and associated test questions. This includes defining scene layouts, placing interactive objects, embedding educational content, and designing assessment questions.
2. ***Student VR Application***: this is the immersive learning environment for students. It is designed to provide a rich and interactive experience where students can navigate through virtual lessons, interact with 3D models and objects, participate in virtual experiments, and undertake knowledge assessments. The VR application focuses on delivering an engaging and intuitive user experience.
3. ***Server Application***: This acts as the center of the entire system. It is indispensable for the seamless operation of

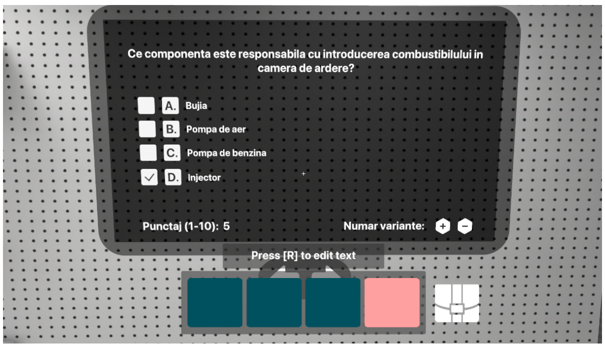

Figure 5. Single-choice question.

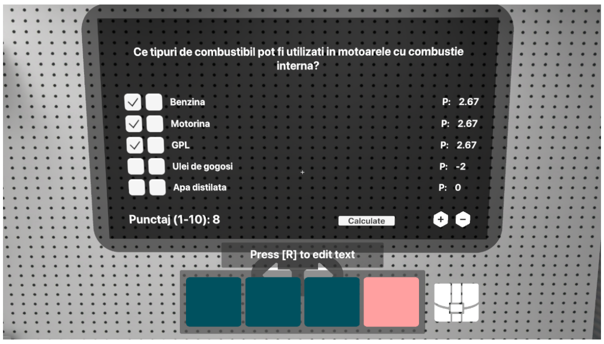

Figure 6. Multiple-choice question.

both the educator's and student's applications. The server facilitates all critical communication, handling requests from both client applications and performing all necessary database operations to store, retrieve, and manage lesson configurations, presentation materials, test data, and student performance records to Lesson Repository.

The technical foundation of the experiments relies on the stack of modern technologies, optimized for performance, scalability, and ease of development:

- **Unity**: has been chosen as the primary development platform for both the Lesson Development Application and the Lesson Execution Application. Unity provides powerful rendering capabilities, extensive asset store, and robust support for mixed reality development, and make it an ideal choice for creating immersive 3D environments and interactive experiences.
- **PostgreSQL**: has been selected as the relational database management system. PostgreSQL is known for its reliability, feature richness, and strong support for complex data types, making it suitable for storing structured lesson configurations, presentation slides, and student performance data.
- **Spring Boot**: has been utilized for developing the Server Application. Spring Boot simplifies the creation of production-ready, stand-alone Spring-based applications,

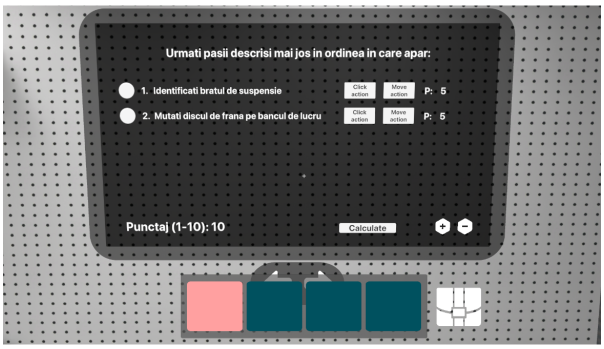

Figure 7. Numbered list question.

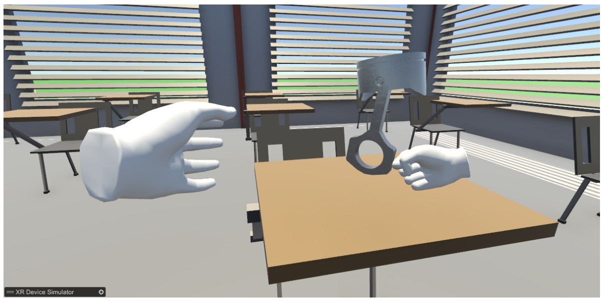

Figure 8. Object interaction within the virtual laboratory.

enabling rapid development of seamless communication between the client applications and the database.

- **Meta Quest 2 Headset and Controllers**: support immersive VR applications. It features inside-out tracking, which uses four cameras to monitor head and hand movements without the need for external sensors. This system supports 6 degrees of freedom (6DOF) tracking. The system also includes a pair of controllers designed for interaction within virtual environments and haptic feedback through vibration, thus confirming button presses or grab interactions and enhancing the sense of physical presence in the virtual environment.

SCENE DESIGN

The professor drags and drops 3D objects from the inventory into the virtual scene, and then sets the position, scales, and rotates them to create an engaging learning environment (Fig. 1).

Object Mobility

This module provides the standard character movement controls within the desktop application's scene editor. Users can navigate the 3D environment using keyboard inputs for translation (e.g., WASD keys for forward, backward, strafing) and mouse inputs for camera rotation (looking around). Crucially, this module also incorporates collision detection to prevent the character from passing through virtual objects or scene boundaries, ensuring a realistic and manageable editing experience.

Object Catalog

The catalog is the central repository of the available assets. It allows the professor, via the desktop application, to browse and select from a library of 3D objects to populate lesson scenes. Additionally, it provides access to various predefined question types that can be incorporated into tests, ensuring a standardized yet flexible content creation process.

Inventory Module

Drawing inspiration from popular game mechanics (e.g. Minecraft), this module provides the professor with an intuitive inventory system (Fig. 9). It features four main, easily accessible slots for frequently used items or tools, complemented by twelve additional slots that are accessible

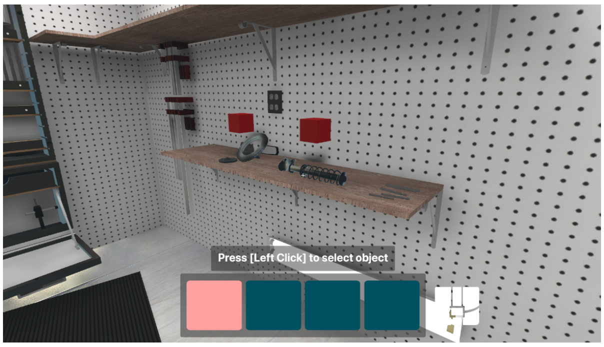

Figure 9. Selecting objects to be placed into the inventory.

via a dedicated “chest” icon. This system allows professors to hold, select, and deploy various types of objects into the virtual environment, simplifying scene construction and interaction design.

LESSON CREATION

The professor creates interactively the lesson by scene of objects, presentations, and questions.

Presentations

The presentation consists of uploading PDF slides and map the content onto a panel (Fig. 4).

Question Creation

This is an important functionality that empowers professors to design and configure diverse types of assessment questions. It supports various questions, including simple single-choice, multiple-choice, and innovative "click action" based questions:

- ***Single Choice Question***: Enter the question text and answer options. Use a radio button to designate the single correct answer (Fig. 5).
- ***Multiple Choice Question***: Enter the question text and multiple answer options. Use checkboxes to select all correct answers. Professors can also set custom scores for incorrect choices (penalties) and how the total score is distributed among correct options (Fig. 6).
- ***Click Action Questions*** (*Numbered List* and *Bullet List*): These are interactive tasks where the professors define a sequence of actions that students must perform by clicking on specific 3D objects in the VR scene (Fig. 8). For instance, "Click on object A, then object B, then object C". The professor can specify if the order of clicks is mandatory (ordered list) or if any correct click contributes to the task completion (bullet list) (Fig. 7).

Saving Lessons

After designing the scene and questions, click "Save Lesson" to upload all configurations and presentations to the lesson repository onto the server. A robust persistence system is vital for saving and loading educational content.

Figure 10. Lessons are uploaded to a whiteboard and executed in the 3D virtual classroom.

Saving Questions

Once professors have configured questions within the desktop application, these configuration files are saved. This configuration file captures all the details of the question, including its type, options, correct answers, and associated scores.

LESSON EXECUTION

Select and Load Lesson

The student browses the available lessons loaded from the server and select one to start.

Loading Questions

For the Lesson Execution Application, questions are dynamically loaded from the repository (Fig. 10). The application sends a request to the server to fetch the relevant configuration file for a specific lesson. Once received, the VR application parses the configuration file and instantiates the presentations, objects, and questions within the virtual scene, making them interactive for the student.

Navigate Virtual Classroom

The student uses the VR controllers (joysticks for movement, buttons for teleportation or snap turns) to navigate through the virtual classroom environment. He interacts with 3D objects, view presentation slides, and explore the lesson's interactive elements.

Test Execution

Once all presentation slides are viewed or the professor's content concludes, a virtual exit door will unlock, allowing the student to enter the designated test room. In the test room, students will encounter the questions configured by the professor. They interact with these questions (e.g., selecting answers, click actions) within the VR environment. After completing the test, answers are automatically submitted to the server for grading. Students can then view their performance, including their grade for the completed lesson, providing immediate feedback on their comprehension.

ACADEMIC PERFORMANCE TRACKING

This system is a core component within the Student VR Application, responsible for:

- ***Monitoring student progress***: It tracks how students interact with the lesson content, including which sections they view, which objects they interact with, and the time spent on various tasks.
- ***Calculating grades***: For assessment questions, the system automatically calculates scores based on correct answers and task completion. For instance, in a multiple-choice question, it evaluates selections against the professor-defined correct answers and scoring rules. For "Click action" tasks, it verifies for instance, if the student performed the required actions in the correct sequence.
- ***Recording performance***: The calculated grades and potentially other performance metrics (e.g., completion time, number of attempts) are then sent to the server to be stored in the Grade model/table, providing a comprehensive record of student academic performance over time.

EXPERIMENTAL VALIDATION

Rigorous experimental evaluations and validations were conducted to ensure the functionality, performance, and usability of the system. Comprehensive testing was crucial to confirm that all three interconnected modules - the Professor Application, the Student VR Application, and the Server - operate reliably and provide high usability.

VRQUIZ Testing

System testing focused on validating the seamless communication and interaction between all components of the educational system.

- *Inter-application Communication* - Extensive tests were conducted to verify the communication flow between the professor application, the student VR application, and the central server. This included verifying that lesson configurations and question data could be successfully uploaded from the professor's application to the server, and then correctly downloaded and rendered by the student's VR application. Similarly, student responses and performance data were tested to ensure accurate transmission back to the server for processing.
- *Network Environment Variability* - A critical aspect of system testing involved evaluating performance across different wireless network environments. This included testing in a standard local area network (LAN) as well as a more restrictive university network.
- *Data Integrity and Consistency* - Tests also focused on ensuring that data transmitted between applications and stored on the server remained consistent and uncorrupted. This involved verifying that uploaded lesson files, converted PDF images, and student grades were accurately saved and retrieved without any loss or alteration of information.

Performance Evaluation

Performance evaluation was conducted from two primary perspectives to assess the system's responsiveness and efficiency under various loads.

- *Application Performance* (Desktop and VR Applications): Both the Professor's Application and the Student's VR Application were tested for their real-time performance. Metrics such as frames per second (FPS) were closely monitored. On average, both applications consistently achieved over 60 frames per second. This is a crucial indicator of good performance, particularly for VR applications, where maintaining a high frame rate is essential to prevent motion sickness, ensure smooth interactions, and deliver a truly immersive experience. A consistent 60+ FPS ensures that visual updates are fluid and responsive to user input, contributing significantly to user comfort and engagement.
- *Server Performance*: The performance of the Server Application was evaluated by measuring response times for various API operations. This included: lesson upload/creation, question configuration updates, slide image uploads, lesson configuration retrieval, grade submission/processing: responsiveness for receiving and processing student performance data.

Usability Evaluation

This section refers to the methodology and expected results in the usability evaluation, focusing on how intuitive, efficient and satisfying the system is for its target users (teachers and students). Up to this stage, the development team has experimentally assessed the possibility of achieving a high level of usability through the adopted technical and technological solutions. This stage will be extended by the actual experimental validation of usability by a group of target users:

- *User Interface (UI) Assessment*: This involves evaluating the clarity, navigability, and aesthetic appeal of both the desktop and VR interfaces.
- *Learnability*: How quickly and easily new users can understand and effectively operate the system without extensive training.
- *Efficiency of Use*: How quickly users can accomplish tasks (e.g., creating a lesson, taking a test, navigate) once they are familiar with the system.
- *User Satisfaction*: Gathering feedback through surveys or interviews to gauge overall satisfaction with the system's functionalities and interaction design.
- *Error Rate*: Observing how often users encounter errors and how easily they can recover from them.

CONCLUSION

The research developed and evaluated the VRQUIZ educational system leveraging Virtual Reality technologies. The system consists of three fully functional and interconnected components: Professor's Application for content creation, Student's VR Application for immersive learning and assessment, and central Server for managing resources and facilitating communication.

The professor can create the lesson completely interactively. All components of a lesson are created interactively: (1) defining, configuring and executing the presentation; (2) describing and executing the questions; (3) executing all types of questions, tasks and scenarios; (4) defining how to calculate the grades corresponding to the answers; (5) managing resources such as lessons, objects, etc.; (6) building the virtual scene of the objects and using them in the educational process.

Table 1. Compare features of the VRQUIZ and similar platforms.

Feature/ Platform	Lesson mng.	Tests mng.	Load materials	Flexible config.
ENGAGEVR			√	√
SANLAB	√	√		√
METAVERSE LEARNING	√	√		
3SPIN			√	√
VRQUIZ	√	√	√	√

Experiments have validated the possibility of achieving a high level of usability through the adopted technical and technological solutions.

Key achievements include:

- *Interactive Lesson Creation*: Professors can create dynamic lessons, integrating PDF presentations, custom 3D objects, and various interactive question types (single-choice, multiple-choice, and contextual "Click actions").
- *Immersive Learning Experience*: Students can engage with educational content in a highly immersive 3D environment, allowing for visual exploration and hands-on interaction with virtual models, significantly enhancing engagement beyond traditional static media.
- *Robust Assessment Tools*: The system supports diverse assessment methods, including performance tracking for interactive tasks, providing a more holistic evaluation of student understanding.
- *Seamless Data Flow*: The server effectively manages all lesson configurations, presentation assets, and student performance data, ensuring a smooth and consistent flow of information between the professor's creation and the student's learning experience.
- *High Performance*: Both the desktop and VR applications consistently achieved over 60 FPS, ensuring a fluid and comfortable user experience, which is particularly critical for VR to prevent motion sickness.
- *Comparison with Existing Solutions*: Unlike many existing VR educational platforms that offer predefined content or limited customization (e.g., EngageVR, Sanlab Learning Technologies, Metaverse Learning UK), the VRQUIZ system provides professors with extensive tools to create and tailor their own lessons and assessments, making it highly adaptable to various curricula and teaching styles (Table 1). It integrates flexible question configuration and a detailed performance tracking system.

Future Developments

Although the VRQUIZ system represents a significant step forward in VR education, there are several possibilities for future improvements and expansions:

- *Multiplayer Functionality*: Implementing real-time multiplayer capabilities would allow multiple students and professors to interact within the same virtual classroom, fostering collaborative learning and direct mentorship.
- *Advanced Interaction Types*: Developing more complex interactive elements, such as virtual laboratories with real process simulations, haptic feedback integration, or natural language processing for voice commands, could further deepen immersion and learning effectiveness.
- *Integration with Learning Management Systems* (LMS): Seamless integration with existing LMS platforms (e.g., Moodle, Canvas) would allow for easier student enrollment, grade synchronization, and broader adoption within established educational infrastructures.
- *AI-Powered Adaptive Learning*: Incorporating Artificial Intelligence could enable the system to adapt lesson content and difficulty in real-time based on individual student performance, providing personalized learning paths.
- *Content Library Expansion*: Developing a comprehensive library of reusable 3D assets and pre-built lesson templates would accelerate content creation for professors.
- *Cross-Platform VR Support*: While untethered headsets are prioritized, expanding support to a broader range of VR hardware and platforms would increase accessibility.
- *Enhanced Analytics*: Providing professors with more detailed analytics on student engagement, common misconceptions, and performance patterns would offer valuable insights for improving pedagogy.
- *Augmented Reality (AR) Integration*: Exploring AR capabilities could allow the system to overlay virtual educational content onto real-world environments, offering unique mixed-reality learning opportunities.
- *Open-Source Contribution*: Releasing parts of the project as open-source components could foster community development and accelerate innovation in VR education.

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