HydroVerse Education: An AI-Assisted Education Framework for Immersive Learning and Training Environments

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Abstract

Hydroinformatics education has traditionally been constrained by pedagogical approaches that fail to adequately convey the complexity of water systems. Virtual Reality (VR) presents a transformative solution by enabling interactive and experiential learning. This study introduces HydroVerse Education, an immersive virtual classroom environment designed to modernize hydroinformatics education by integrating virtual reality and artificial intelligence. Utilizing advanced technologies such as Unreal Engine, Metahuman, and Generative AI, the platform generates an interactive virtual classroom with immersive communication and knowledge generation features. Central to the framework is an AI-driven virtual instructor, enabling real-time voice-based interactions that provide personalized guidance tailored to diverse learning styles. The HydroVerse Education promotes engagement and understanding through realistic simulations of complex hydroinformatics scenarios, bridging the gap between theoretical concepts and practical application. Addressing the growing need for accessible and cost-effective educational tools, the platform offers flexible and adaptive learning experiences to prepare educators, instructors and researchers for advanced challenges. This study details the system's development, architecture, and capabilities, explores its transformative potential for education, and discusses challenges and future directions for integrating virtual reality into any domain.

Keywords: Hydroinformatics, Extended Reality (XR), Generative AI, Metahuman, Human Computer Interactions, Scientific Communication

1. Introduction

In the not-so-distant future, the landscape of education may undergo significant changes as virtual reality and artificial intelligence become a key part of learning process (Hu-Au & Lee, 2017). Instead of relying on static diagrams, students can engage with dynamic environments, such as virtual hurricanes or underwater ecosystems (Brennan et al., 2019). This shift marks a departure from traditional educational methods, offering students new opportunities for engagement and practical learning (De Freitas et al., 2015; Harasim, 2000; Sajja et al., 2025a).

Conventional educational approaches, such as textbooks, lectures, and hands-on activities, often struggle to provide the interactive experiences needed to fully grasp complex subjects (Regan et al., 1996). Virtual reality presents a promising alternative by creating simulated environments that replicate real-world scenarios or abstract concepts (Korkut et al., 2023). These environments capture students' attention and enhance their understanding of complex topics, offering a more effective way to learn (Moşteanu, 2021).

The exploration of virtual reality (VR) technology within educational settings has gained considerable attention over the past decade for its potential to revolutionize traditional teaching methods (Al-Ansi et al., 2023). VR provides engaging and interactive learning environments that address the shortcomings of static, text-based, and lecture-driven approaches (Overskott et al., 2024; Sermet & Demir, 2022). This section examines existing literature on VR applications in education, with a specific focus on hydroinformatics, and highlights the gaps this study seeks to address (Mudiyanselage et al., 2025).

1.1. Virtual Reality Applications in Education

Virtual reality (VR) has become a powerful tool in education, offering engaging and practical learning experiences across various domains (Marougkas et al., 2023; Daniela, 2020). It is particularly effective in STEM fields, where it bridges the gap between abstract theoretical concepts and hands-on applications (Anoling et al., 2024; Sermet & Demir, 2019). Studies have shown that VR can significantly improve student engagement, comprehension, and skill development by simulating real-world scenarios within a controlled environment (Goi, 2024; Sermet & Demir, 2020).

For instance, Koolivand et al. (2024) demonstrated the benefits of integrating VR with haptic feedback systems in healthcare education, leading to enhanced knowledge retention and practical skills among dental students. Similarly, Bores-García et al. (2024) reported increased motivation and participation among students in physical education courses using VR. However, these advancements are accompanied by challenges, including high implementation costs and limited adaptability to diverse learning styles (Ramesh et al., 2024; Omoseebi et al., 2024).

Systematic reviews, such as the one conducted by Marougkas et al. (2023), highlight the critical role of adaptive content and personalized learning features in maximizing the effectiveness of VR platforms. Combining these features with gamification elements has been shown to improve engagement and learning outcomes (Liu et al., 2023; Rivera et al., 2021; Jayalath et al., 2022).

Nevertheless, further research is required to address issues of inclusivity and scalability, ensuring that VR-enhanced education can benefit a broader range of learners.

1.2. Virtual Reality Applications in Hydrological Education

The adoption of virtual reality (VR) in hydrological education is still in its early stages, but it shows significant potential for advancing the understanding of complex water systems (Rahmani et al., 2025). Georgakakos and Knighton (2024) highlighted the value of incorporating diverse teaching methods in hydrology, advocating for tools that provide interactive and engaging learning experiences. Their research suggests that VR can enhance student engagement and critical thinking by simulating natural phenomena such as river flows, flooding events, and ecosystem dynamics.

Innovative Virtual Learning Experiences (VLEs), like virtual field trips, have demonstrated success in related fields such as geography education. For example, Gielstra et al. (2024) developed virtual pathways for exploring glacial landscapes, enabling students to interact with remote natural environments. Similar approaches in hydroinformatics could be used to simulate water resource management challenges, providing students with opportunities to test solutions in a risk-free, controlled setting.

Furthermore, studies on the use of the Metaverse in education, such as those by Alkhwaldi (2024), emphasize the importance of user characteristics and technology adoption. These findings highlight the necessity of creating accessible and user-friendly VR systems tailored to the unique challenges of specific domains, ensuring broad applicability and effective learning outcomes.

1.3. Intelligent Assistants in Hydrological Virtual Applications

The integration of AI-driven assistants into advanced educational environments has significantly expanded the capabilities of VR platforms. Intelligent teaching assistants, powered by natural language processing (NLP) models like GPT-3 and GPT-4, facilitate dynamic and personalized interactions (Ravindran et al., 2025). For example, Sajja et al. (2025b) introduced a curriculum-specific AI assistant that enhanced student engagement and streamlined course delivery. Zhong and Liu (2021) examined the use of VR teaching assistants in experimental courses, demonstrating their effectiveness in creating interactive and engaging learning environments. These AI-driven assistants are capable of adapting to individual learner needs, providing instant feedback, and supporting deeper comprehension of complex topics (Jegede et al., 2024; Strielkowski et al., 2025; Pursnani et al., 2024).

In hydroinformatics, the adoption of ontologies, knowledge systems, and AI-powered assistants remains in its early stages (Baydaroglu et al., 2023; Kadiyala et al., 2024). However, technologies such as Metahuman and OpenAI offer promising opportunities to address challenges in conceptual understanding and student engagement (Gacu et al., 2025). By enabling realistic and adaptive interactions, these systems have the potential to transform the field, bridging the gap between theoretical knowledge and practical application (Singh et al., 2024; Samuel et al., 2024; Shrestha et al., 2025).

1.4. HydroVerse Education: AI-Assisted Immersive Education Framework

This research study introduces an innovative education framework designed to transform the study and skill development of hydroinformatics curriculum. The system leverages virtual environment technology, natural language processing, and highly realistic human avatars to provide interactive learning experiences and communication channels. Utilizing advanced platforms such as Unreal Engine, Twinmotion, Metahuman, and OpenAI, the education room redefines the traditional classroom by creating a dynamic and engaging learning environment.

At the core of this system is Metahuman, an artificial instructor that serves as the central element of the simulated classroom. Metahuman feature enables students to interact with avatars, creating personalized and engaging learning experiences (Alam et al., 2022; Nasir et al., 2024). This innovation represents a significant step forward in educational methodologies within the field of hydroinformatics, opening new possibilities for effective and accessible learning.

The project aims to utilize Metahuman as an artificial instructor to create a simulated classroom environment that facilitates communication between students and avatars. By improving engagement and learning outcomes, the system addresses longstanding challenges in education. This project provides a foundation for advancing educational methodologies through the integration of virtual reality technologies.

2. Methods

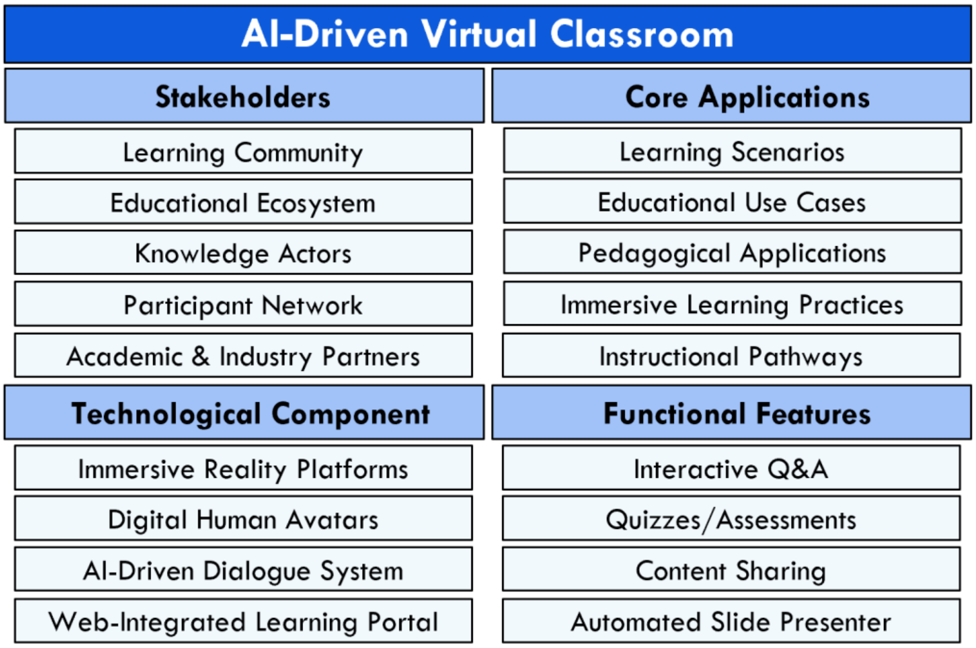
This section provides an integrated overview of the HydroVerse Virtual Classroom Hub, outlining both its architectural design and methodological foundations. The discussion begins by establishing the scope and purpose of the system, situated it within the broader context of immersive learning and AI-driven interaction. It then turns to the mechanisms of data sources and content integration, which define how diverse instructional materials are incorporated, processed, and delivered within the virtual classroom. Finally, the system architecture is examined in detail, highlighting the interaction between XR technologies, AI knowledge layers, and web-based components that collectively create a seamless and adaptive educational environment.

2.1. Scope and Purpose

This research project introduces the design and implementation of an AI-driven virtual classroom that applies advanced virtual reality technologies to transform teaching and learning. The system offers students an interactive 3D classroom environment where they can attend lectures, collaborate with peers, and engage in practical learning activities. An intelligent Metahuman instructor facilitates real-time communication, guidance, and personalized feedback, enabling dynamic teacher–student interactions that both simulate and expand upon traditional classroom experiences.

The technological framework comprises four foundational components. Immersive reality platform establishes 3D environments that support interactive and spatially rich learning experiences. Digital human avatars function as embodied agents, enabling natural interaction and enhancing the sense of presence in the classroom. An AI-driven dialogue system ensures real-time, context-aware communication, providing adaptive feedback and personalized instruction. The web-integrated learning portal acts as a connective interface, linking virtual environments with accessible online resources, course materials, and collaborative tools.

The core applications emphasize advancing educational practice through adaptive and experiential methods. Learning scenarios replicate authentic classroom and real-world contexts, enabling direct engagement with subject matter. Educational use cases demonstrate how the system can be applied across disciplines to address diverse instructional requirements. Pedagogical applications focus on embedding evidence-based teaching strategies within virtual environments to promote effective knowledge transfer (Vorsah et al., 2025; Liaw et al., 2022; Rajaram, 2021). Immersive learning practices highlight the use of embodied, interactive experiences to deepen comprehension and retention (Xu et al., 2022; Beck et al., 2023; Kuhail et al., 2022). Instructional pathways provide structured trajectories for learners, aligning virtual activities with curricular goals and personalized outcomes.



AI-Driven Virtual Classroom

Stakeholders	**Core Applications**
Learning Community	Learning Scenarios
Educational Ecosystem	Educational Use Cases
Knowledge Actors	Pedagogical Applications
Participant Network	Immersive Learning Practices
Academic & Industry Partners	Instructional Pathways
Technological Component	**Functional Features**
Immersive Reality Platforms	Interactive Q&A
Digital Human Avatars	Quizzes/Assessments
AI-Driven Dialogue System	Content Sharing
Web-Integrated Learning Portal	Automated Slide Presenter

Figure 1: Conceptual framework of AI-Driven Virtual Classroom

The stakeholders span multiple dimensions of the educational and research landscape. The learning community, including students, educators, and lifelong learners, benefits from direct access to interactive instructional environments. The educational ecosystem, encompassing universities, research institutes, and academic programs, employs the system to extend global reach and encourage innovation in teaching and dissemination. Knowledge actors, such as researchers, instructors, and presenters, gain effective tools for communicating findings and engaging audiences. The participant network, made up of peers, collaborators, and attendees, facilitates knowledge exchange and collective learning. In addition, academic and industry partners serve as strategic contributors, integrating research, technology, and professional expertise to enhance impact and scalability across domains.

2.2. Data Sources and Content Integration

The system supports a wide variety of user-contributed content, enabling instructors, learners, and external participants to integrate diverse resources into the Immersive Reality Platforms. Supported formats include PDFs, images, videos, hyperlinks, YouTube streams, and presentation files. Users can prepare structured tutorials or share real-world experiences on a given subject, culminating in quiz-based assessments that allow for interactive evaluation of understanding.

All uploaded content is processed and structured to support multimodal delivery. Visual materials are rendered directly within the Immersive Reality Platforms, while textual materials are transformed into accessible narration through AI-Driven Dialogue Systems. Generative AI pipelines perform text extraction, segmentation, and semantic indexing across documents and media, enabling context-aware responses to user queries.

During a session, learners may directly interact with Digital Human Avatars connected to the generative AI system. This allows them to ask questions about the integrated content and receive both textual and synthesized voice responses. Additionally, instructors can join the class through integrated conferencing (e.g., Google Meet) to supervise learning, provide real-time feedback, and address questions beyond the AI-driven interaction. The environment itself is simulated as a classroom within the Web-Integrated Learning Portal, ensuring that data sources, instructional content, and interactive features are seamlessly integrated into a cohesive, collaborative learning experience.

2.3. System Architecture

The HydroVerse Virtual Classroom Hub is structured around a modular architecture that integrates multiple layers of functionality into a unified learning environment. The system is composed of five interconnected modules, each responsible for a distinct aspect of classroom operation, while collectively ensuring interaction between users, AI agents, and instructional content. At its core, Unreal Engine provides the foundation for rendering the virtual environment, managing high-fidelity graphics, and supporting immersive interaction through digital avatars.

XR Interaction Environment: The Virtual Environment Module provides the foundation for constructing an interactive 3D classroom designed to replicate the dynamics of face-to-face learning within an immersive digital space. Leveraging Unreal Engine, the system employs advanced rendering pipelines such as Lumen and Nanite to achieve real-time global illumination, detailed textures, and dynamic lighting effects (Berrezueta-Guzman et al., 2025; Li et al., 2024; Wass et al., 2024). These visual capabilities are combined with a physically based rendering (PBR) workflow that ensures material consistency and realism, while skeletal animation and inverse kinematics facilitate lifelike avatar movement. Hardware integration plays a crucial role in enhancing the user experience. Full compatibility with VR headsets enables motion tracking, spatial audio, and teleportation features, all of which contribute to presence and natural interaction within the classroom.

The environment itself is intentionally structured to reflect conventional educational spaces, incorporating lecture boards, seating arrangements, and pedagogical tools that reinforce the sense of familiarity. Beyond environmental design, the module supports seamless access to learning resources. Through an embedded content delivery system, users can open, present, and interact with diverse educational materials without leaving the immersive setting.

AI Knowledge Generation Layer: The AI Knowledge Generation Layer is responsible for enabling advanced natural language processing and intelligent response generation within the virtual classroom. By integrating large language models (LLM), this layer connects directly to structured instructional content, ensuring that user interactions are both contextually relevant and pedagogically accurate (Pirjan et al., 2024; Chen et al., 2024; Shahzad et al., 2025). When learners pose questions, the system draws on preprocessed class materials-including documents, presentations, and multimedia resources-by applying semantic indexing and contextual mapping. This process allows the AI to generate coherent, precise, and domain-specific responses. The outputs are not limited to text; they are seamlessly converted into synthesized speech and delivered through Digital Human Avatars, creating a natural and interactive communication channel. This design transforms the avatar into more than a visual presence: it functions as an intelligent mediator capable of supporting dialogue, clarifying content, and reinforcing instructional objectives. In doing so, the AI Knowledge Generation Layer ensures that knowledge delivery is adaptive, immersive, and aligned with both learner needs and the broader classroom context.

Adaptive Virtual Presenter: The Adaptive Virtual Presenter functions as the central interactive agent within the virtual classroom, designed to merge advanced animation technologies with conversational AI. Developed through Unreal Engine's character rendering pipeline, the presenter is capable of delivering dynamic, high-fidelity interactions that closely resemble human communication. Its primary role is to present summarized instructional material, moderate discussions, and engage learners through real-time question-and-answer exchanges. A critical component of this module lies in its precise synchronization between spoken audio and avatar animation. Lip movements, facial expressions, and gestures are algorithmically aligned with synthesized speech to enhance realism and foster immersion. This multi-modal feedback loop requires careful orchestration across APIs, animation systems, and audio pipelines to achieve both accuracy and low-latency performance. The integration of conversational AI within the Adaptive Virtual Presenter underscores a systems-oriented approach that prioritizes interdisciplinarity, combining computer graphics, artificial intelligence, and educational technology. These choices were guided not by tool availability but by their ability to ensure natural dialogue, expressive delivery, and seamless performance.

Presentation Portal: The Web-Integrated Learning Portal acts as the primary interface for curating and accessing instructional content within the immersive environment. It is designed to support a broad spectrum of data formats, including documents, images, videos, hyperlinks, and live-streamed resources, all of which can be incorporated seamlessly into classroom activities. This portal is not merely a repository but an interactive gateway. Learners can prepare and share tutorials, present subject-specific experiences, or construct quizzes that extend the instructional cycle from content delivery to assessment. Instructors retain oversight through integrated presentation and supervisory features, ensuring that human-led guidance complements AI-mediated support. Functionally, the portal underpins the immersive classroom by synchronizing content with the broader system architecture. It bridges external resources and internal XR delivery, guaranteeing that educational materials remain accessible, adaptable, and contextually embedded within the learning experience.

3D Media and Objects: The virtual classroom is further enriched through the integration of 3D media and interactive objects. This includes digital twins, which replicate real-world systems or equipment in precise detail, enabling learners to engage with accurate virtual representations for training, experimentation, or analysis. Complementing these are 360° images and videos, which immerse users in panoramic scenes to simulate real environments, field visits, or situational contexts that would otherwise be inaccessible. Additionally, 3D objects can be imported and manipulated within the environment, offering learners opportunities to visualize and interact with complex structures or conceptual models in ways that enhance understanding and retention.

Instructor Collaboration Panel: The Instructor Collaboration Panel extends the functionality of the virtual classroom by enabling direct, real-time communication between learners and instructors. While the Adaptive Virtual Presenter and AI Knowledge Generation Layer provide automated explanations and context-based responses, certain learning scenarios demand more nuanced discussion or the presence of a human instructor. This module fulfills that need by integrating live video conferencing tools, allowing instructors to join sessions, supervise class activities, and provide personalized feedback.

Through this feature, learners can transition from AI-mediated interaction to synchronous engagement with a human educator. Such flexibility supports mentorship, clarification of complex concepts, and collaborative problem-solving that may exceed the capabilities of automated systems alone. The Instructor Collaboration Panel is embedded within the same immersive environment, ensuring continuity of experience and preserving the flow of classroom activities**.**

Architecture Model: The architecture of the HydroVerse Virtual Classroom Hub is organized into three interconnected layers that together create a seamless immersive learning experience. At the foundational layer, the system incorporates Twinmotion, voice input, and the navigation handle. Twinmotion supports the creation and facilitation of the virtual environment, ensuring that the classroom space is both interactive and visually coherent. Voice Input enables natural communication between learners, instructors, and the Adaptive Virtual Presenter, while the Navigation Handle provides intuitive controls for exploring the classroom and interacting with its various elements.

The section under the HydroVerse Virtual Classroom Hub integrates the Adaptive Virtual Presenter, the AI Knowledge Generation Layer, and 3D media & objects within the Unreal Engine–based environment. These components establish real-time, AI-driven interactions in the virtual classroom. Learners can engage with digital human avatars that present material, moderate discussions, and provide contextual responses powered by the AI knowledge engine. This layer ensures immersion, presence, and intelligent dialogue within the VR space.

The Web Section connects immersive experience with web-based systems, including the Presentation Portal and the Instructor Collaboration Panel. The Presentation Portal functions as the gateway for managing and presenting diverse learning materials, while the Instructor Collaboration Panel enables synchronous engagement between students and instructors through integrated conferencing tools. Together, they extend the classroom experience by combining AI-mediated interactivity with direct human guidance.

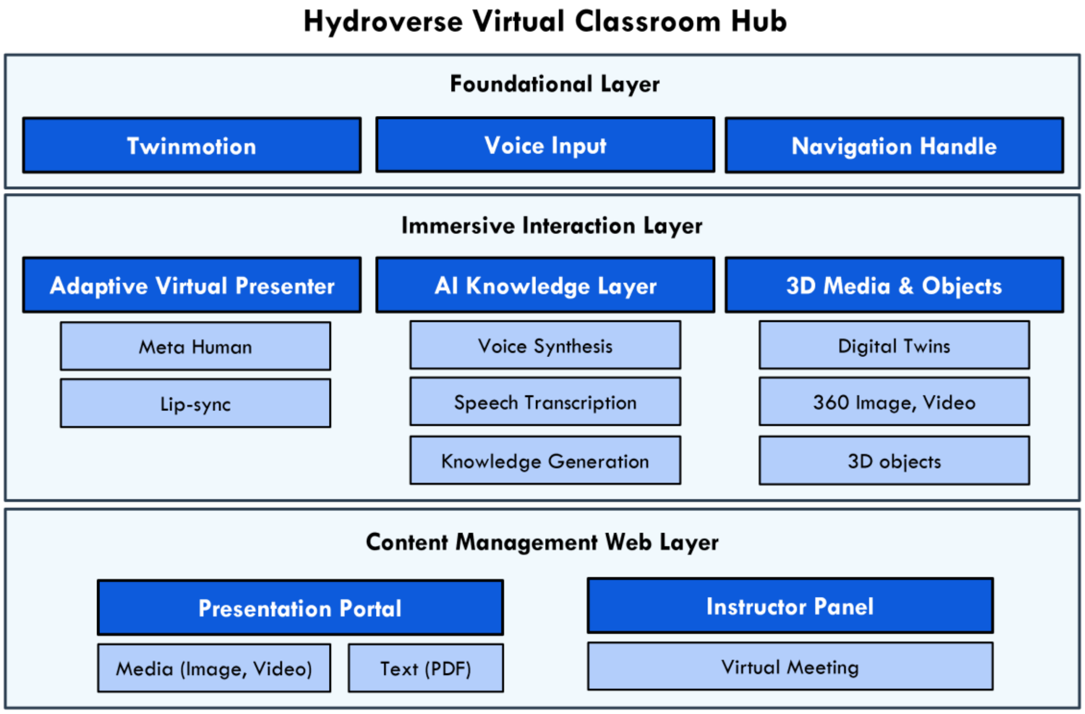


Figure 2: System Architecture of AI-Driven Virtual Classroom.

3. Results

The results of this study demonstrate how the proposed system translates its architectural design into functional components within the immersive learning environment. Each feature was evaluated in terms of its ability to enhance interactivity, accessibility, and pedagogical effectiveness. The following subsections present the major modules of the system, highlighting their roles in supporting dynamic content delivery, adaptive instruction, and real-time learner engagement.

3.1. Presentation Portal

In the virtual classroom, learners enter an immersive environment equipped with access to the educational portal. The Image Presentation section allows them to view PDFs, research documents, and reference materials as part of structured lessons. Here, Avatar introduces the session and provides short explanations of key concepts, ensuring that content is contextualized for learners. As shown in Figure 3, the Presentation Portal provides learners with access to structured materials such as PDFs, slideshows, videos, and quizzes, all organized within an interactive class portal.

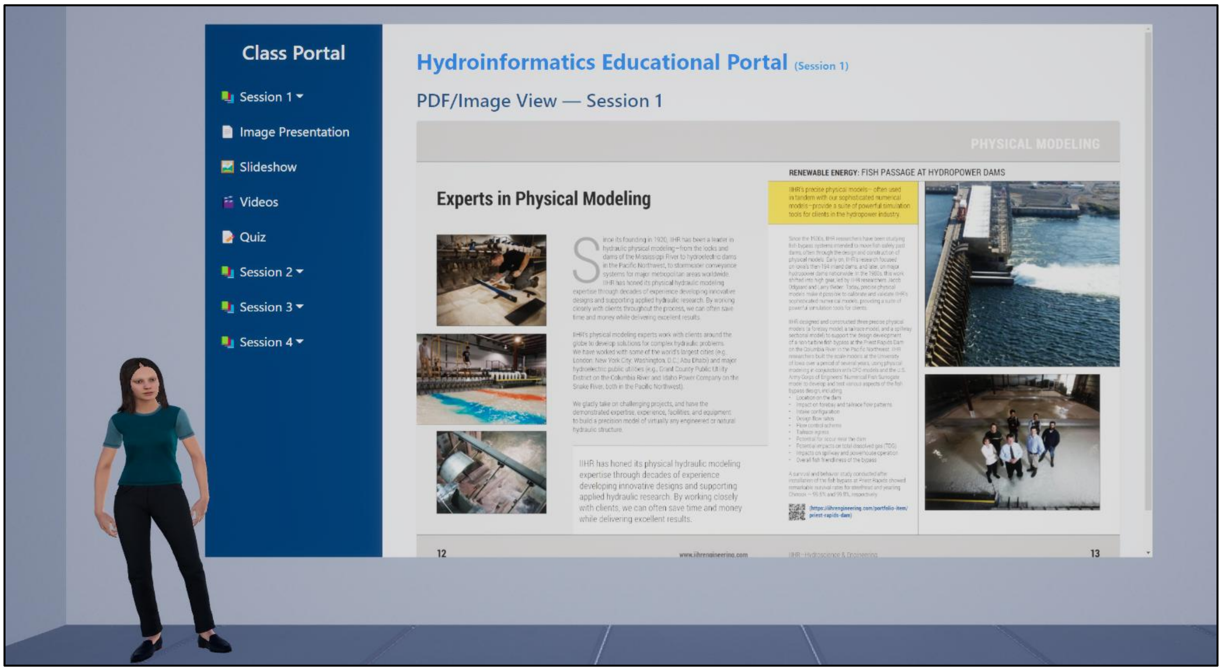
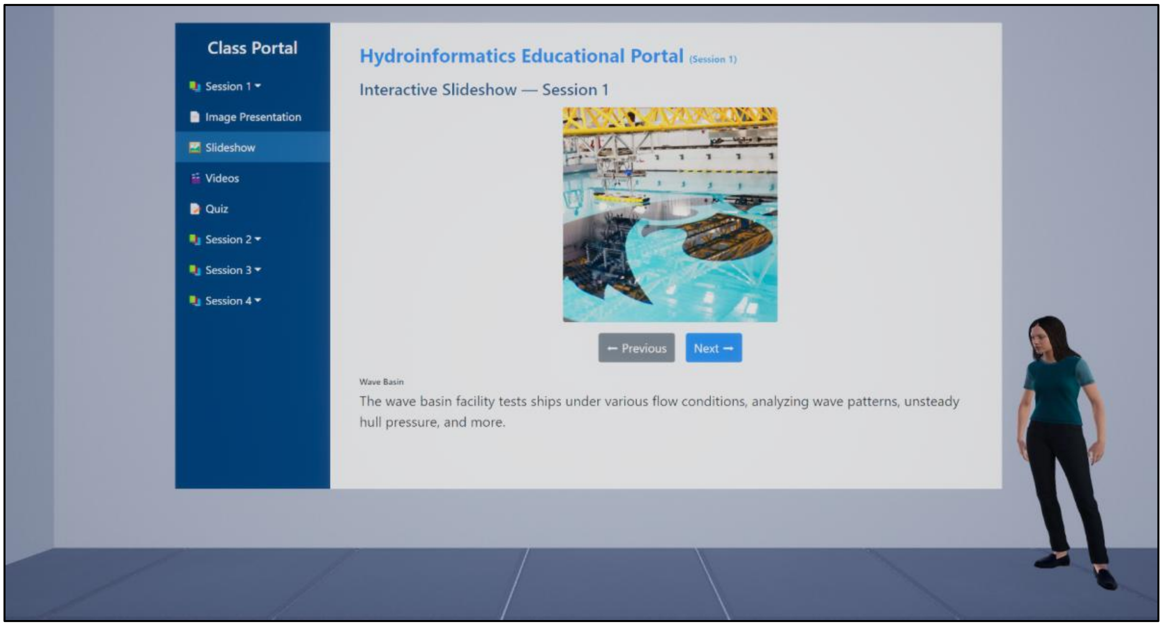


Figure 3: Presentation Portal in the Hydroinformatics Education Hub

The Slideshow feature provides a structured presentation interface within the virtual classroom. Each slide page is designed with a central display area for the content, accompanied by navigation controls that allow users to move forward or backward. Content on these slides can include text, images, videos, or a combination of media formats, giving instructors and learners flexibility in how materials are presented. The Virtual Instructor Avatar explains each slide, highlights key points, and answers learner questions, while users control the flow with navigation tools. As shown in Figure 4, the Slideshow interface enables interactive navigation of session content.

In the Video Lectures section, the page displays a central video player with navigation controls (Previous/Next) beneath it, allowing learners to move between recordings. Each video is accompanied by a short description or chapter label for context. The Avatar provides brief introductions and summaries for the videos and is available to answer learners' questions about the content. Figure 5 presents the Video Lectures section, offering recorded content with navigation tools.

In the Quiz section, the page presents a central question with supporting content, which may include text, images, or embedded videos. Below the question, learners select from multiple-choice options and navigate across quiz items. This design supports flexible assessment formats, ranging from factual recall to applied problem-solving based on visual or video prompts. The Avatar guides learners through each question, clarifies instructions, and provides immediate feedback, creating an interactive and supportive evaluation process. Figure 6 highlights the Quiz feature, which engages learners through interactive knowledge checks with immediate feedback.



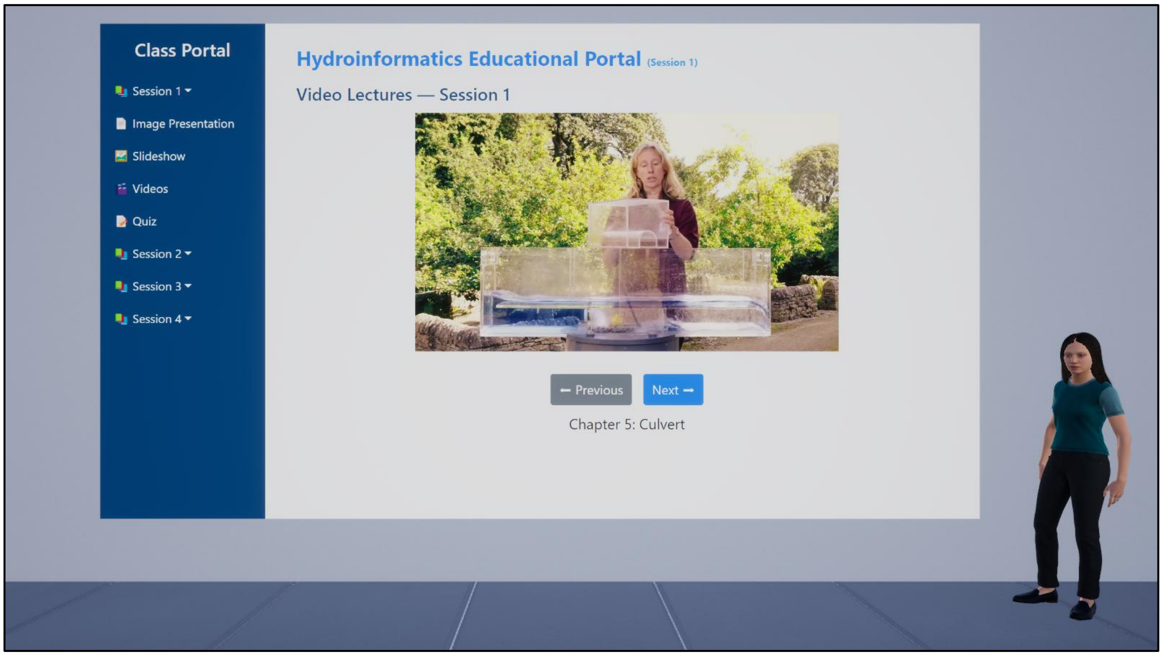
Hydroinformatics Educational Portal (Session 1)

Interactive Slideshow — Session 1

Wave Basin

The wave basin facility tests ships under various flow conditions, analyzing wave patterns, unsteady hull pressure, and more.

Figure 4: Slideshow feature in the Hydroinformatics Educational Portal.

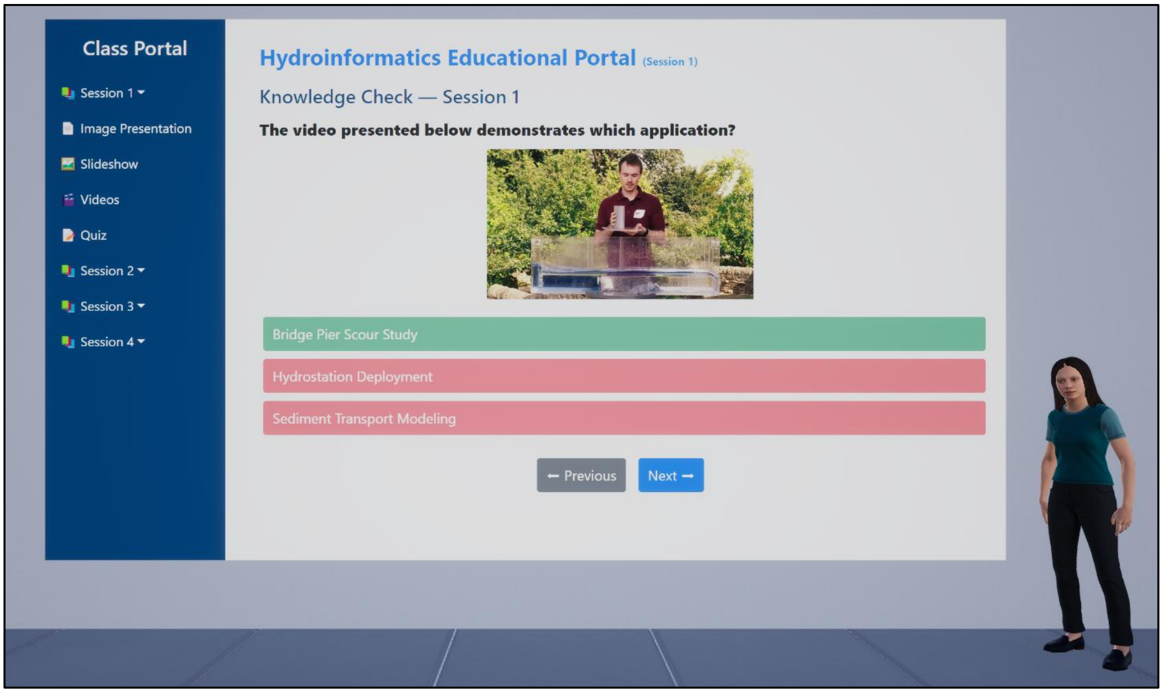


Hydroinformatics Educational Portal (Session 1)

Video Lectures — Session 1

Chapter 5: Culvert

Figure 5: Video Lectures in the Hydroinformatics Educational Portal (see JBA Trust, ca. 2020).



Hydroinformatics Educational Portal (Session 1)

Knowledge Check — Session 1

The video presented below demonstrates which application?

Bridge Pier Scour Study

Hydrostation Deployment

Sediment Transport Modeling

Figure 6: Quiz section in the Hydroinformatics Educational Portal.

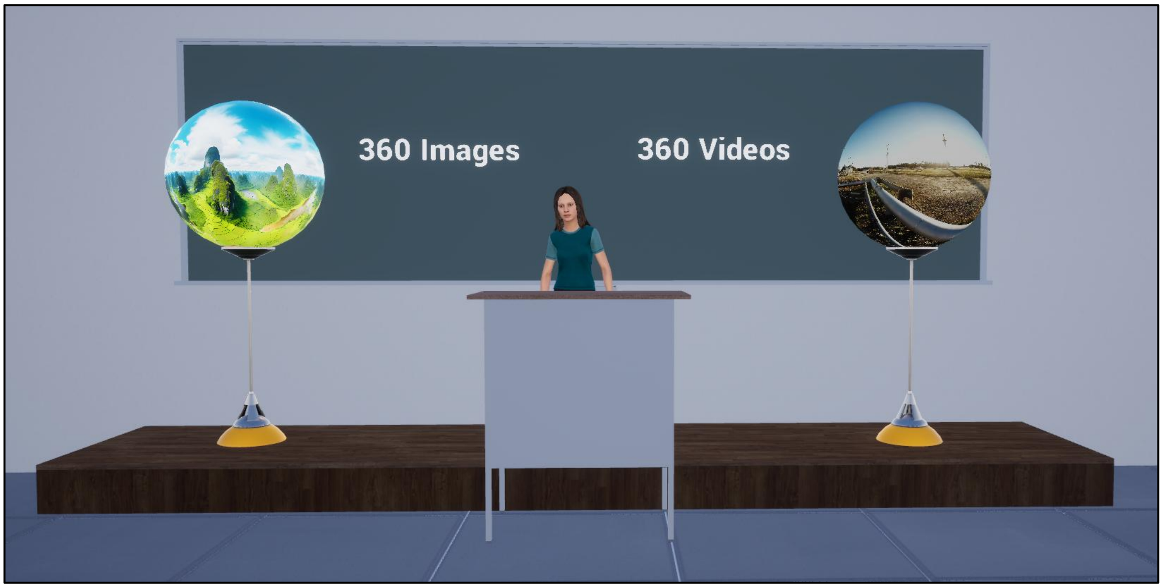


Figure 7: 360 Images and Videos in the hydroinformatics Educational Portal.

3.2. Integrated HydroVerse Learning Environment

Beyond conventional media, the system incorporates 360° images and videos, 3D models, and digital twins. To engage with 360° content, learners are transferred to a dedicated immersive level where they can explore panoramic scenes and environments in full perspective. Digital Twins and 3D objects, such as Earth models or engineered structures, allow learners to interact directly with the objects by rotating, scaling, or examining details to enhance understanding. Throughout these interactions, the Avatar introduces the objects, explains their context, and responds to learner questions, ensuring that engagement with complex visual materials is both guided and meaningful. Figures 7 and 8 demonstrate the use of 3D models and digital twins for interactive learning within the immersive classroom.

Figure 8: 3D models and digital twins in the hydroinformatics Educational Portal.

3.3. Adaptive Virtual Presenter

The presence of an Avatar powered by ACE Metahuman and OpenAI introduces a transformative element to the virtual classroom. Unlike static media or pre-recorded lectures, the Avatar acts as a dynamic facilitator, capable of presenting content, responding to learner questions, and adapting explanations in real time. When learners enter the immersive space, the Avatar not only welcomes them but also provides context for each type of content, whether it is a research paper, slideshow, video demonstration, quiz, or interactive 3D model.

For example, in a 3D object interaction session, learners might explore a digital twin of a hydraulic structure. While they manipulate and inspect the model, the Avatar explains its function, highlights key features, and answers spontaneous questions such as “What happens if this section fails under high flow conditions?” The system draws from structured content and AI knowledge layers to deliver immediate, tailored responses, ensuring that engagement goes beyond observation to become active inquiry.

The Adaptive Virtual Presenter serves as the central interactive agent within the virtual classroom environment. Developed using Unreal Engine's character rendering pipeline and ACE Metahuman technology, the presenter is integrated with OpenAI's language models to enable real-time conversational interactions.

The Avatar performs several functions within the classroom. It delivers structured presentations of instructional material, including introductions to research papers, slideshows, video demonstrations, quizzes, and 3D models. When learners pose questions, the system retrieves relevant information from preprocessed course content through semantic indexing and generates context-specific responses. These responses are converted to synthesized speech and synchronized with Avatar's facial animations and lip movements.

During interactive sessions with 3D objects, such as digital twins of hydraulic structures, the Avatar provides explanatory narration as learners manipulate and inspect the models. For example, when a learner asks, "What happens if this section fails under high flow conditions?", the system draws from the structured knowledge base to formulate and deliver an immediate verbal response through the Avatar.

The synchronization between audio output and avatar animation is achieved through algorithmic alignment of phonemes to facial expressions and mouth movements. This process operates in real-time with measured latency to maintain the flow of interaction. The Avatar also manages transitions between different content types within the virtual classroom, maintaining continuity as learners move from one learning activity to another.

3.4. Instructor Panel

The Instructor Panel extends the functionality of the virtual classroom by enabling teachers, professors, or advisors to join sessions at designated times. Through this feature, instructors can actively supervise classroom activities, monitor learner engagement, and ensure that the overall process remains structured and under control. Their presence provides an additional layer of guidance and oversight that complements the automated support offered by the Avatar.

In addition to supervision, the Instructor Panel plays a critical role in addressing complex questions or situations where the Avatar's AI-generated responses may not be sufficient. In these cases, instructors can intervene to provide clarification, deliver nuanced explanations, or facilitate deeper discussions. This combination of automated assistance and human expertise ensures that learners benefit from both the scalability of AI-driven interaction and the depth of instructor-led mentorship.


This browser version is no longer supported. Please upgrade to a supported browser.

Please wait until a meeting host brings you into the call

Figure 9: Instructor Panel in the HydroVerse Virtual Classroom Hub.

For example, a student working through a lesson may encounter a concept that the Avatar cannot fully clarify. Through the Instructor Panel, the student sees that their professor is available for live supervision during the session. The student submits a request, and the professor joins the virtual classroom at the scheduled time to provide direct explanation and guidance. The professor observes the student's interaction with the materials, answers additional questions, and ensures that the learning process remains on track. As illustrated in Figure 8, the Instructor Panel allows seamless integration of live instructor participation using Virtual Meet within the HydroVerse Virtual Classroom Hub, ensuring that learners can transition smoothly from AI-driven assistance to real-time human mentorship without leaving the immersive environment. Figure 8 showcases the Instructor Panel, which enables live supervision and guidance within the immersive classroom.

4. Framework Evaluation and Assessment

To evaluate the system's overall efficiency, responsiveness, and user experience across both immersive and web-based environments, a set of structured performance tests was conducted. These included real-time tracking of rendering behavior, hardware utilization, and AI pipeline responsiveness, along with comparisons of system load with and without active Metahuman processes. The analysis focused on critical factors such as initialization time, frame rate reliability, avatar animation responsiveness, and consistency under sustained use. In parallel, the web-based modules (Poster Selection, Poster Details, Inquiry Story, and Research Bridge Live) were audited using Google Lighthouse to measure accessibility, SEO, and interactive performance. Collectively, these evaluations offer a thorough understanding of the platform's technical stability and its capacity to support immersive, AI-driven scientific communication.

Test Environment: All evaluations were performed on a high-performance desktop system featuring an Intel Core i9-14900KF processor (24 cores, up to 6.0 GHz), 32 GB of DDR5 RAM running at 5600 MT/s, and an NVIDIA GeForce RTX 4080 SUPER GPU with 16 GB of GDDR6X memory. The virtual reality experience was delivered using a Meta Quest 3 headset connected through Link, with the runtime managed under the OpenXR framework on Windows 11 Home. This setup provided a consistent testing environment, minimized hardware-induced latency, and ensured reliable performance for assessing rendering quality, user interaction, and AI integration within Unreal Engine.

Loading and Frame Rate Performance: Across five test sessions, the HydroVerse Virtual Classroom Hub consistently achieved rapid initialization, with total load times averaging about 0.12 seconds in Unreal Engine. Each 120-second run engaged all core modules under user interaction, including poster exploration, Inquiry Story navigation, and Research Bridge access, alongside the fully active Metahuman avatar delivering presentations and responses. Frame rate performance showed strong overall stability, with an average of approximately 118.7 FPS, though minimum FPS occasionally dipped to around 2.99 during intensive events. These results demonstrate efficient load performance and generally high responsiveness, while also indicating rare but significant frame drops under peak system demand.

Resource Usage Comparison: System monitoring revealed that resource utilization remained very low under the tested conditions. CPU usage averaged 3% at 5.6 GHz and 43 °C, while GPU usage was only 14% at 495 MHz and 33 °C. These results indicate that the platform ran efficiently within system limits, with ample headroom for additional computational loads such as real-time Metahuman animation or lip-sync processing, ensuring stable and uninterrupted interaction.

Presentation Portal Performance and Analysis: An evaluation of the web-based modules within the virtual conference platform was conducted using Google Lighthouse. The Education Portal Sessions page demonstrated excellent results, scoring 98 in Performance, 98 in Accessibility, 100 in Best Practices, and 82 in SEO. Core Web Vitals confirmed efficient responsiveness, with First Contentful Paint (FCP) at 0.5 seconds, Speed Index at 0.5 seconds, Largest Contentful Paint (LCP) at 1.1 seconds, Total Blocking Time (TBT) at 0 ms, and Cumulative Layout Shift (CLS) at 0, indicating smooth rendering and stability.

Accessibility performance was also high (98), with only minor recommendations such as correcting the sequential order of heading elements. Compliance with Best Practices was flawless (100), confirming strong alignment with modern security and coding guidelines. The SEO score (82), while decent, was somewhat reduced due to missing meta descriptions and non-crawlable links, issues that could be resolved with simple updates.

5. Discussion

The discussion explores the implications of this study, emphasizing the transformative potential and associated challenges of integrating Virtual Reality (VR) technology into educational systems. The introduction of virtual educational environments, such as the one presented in this study, highlights a significant evolution in how students interact with and understand complex concepts. By leveraging cutting-edge technologies, these systems aim to address longstanding limitations in traditional pedagogical approaches, offering a more dynamic, interactive, and inclusive framework for education.

Through the lens of hydroinformatics education, this study demonstrates the capacity of virtual learning environments to connect theoretical knowledge with practical application. The integration of AI-powered instructors and dynamic simulations establishes a foundation for broader applications of these technologies across various educational contexts, emphasizing the scalability and versatility of the platform (De Rus et al., 2022). This discussion also examines the wider implications of adopting such innovations, including their potential impact and inherent limitations.

5.1. Potential Impact of Virtual Educational Rooms with Interactive Instructors

The integration of Virtual Reality (VR) technology into educational systems represents a paradigm shift in pedagogical methodologies (Shihab et al., 2023). This study highlights the potential of virtual educational environments equipped with interactive instructors to transform hydroinformatics education and beyond. By offering dynamic learning spaces facilitated by Metahuman avatars, this platform enables students to engage with complex concepts in an intuitive and interactive manner.

One of the most significant impacts of immersive technologies is its ability to enhance engagement and experiential learning (Asad et al., 2021). Realistic simulations and real-time interactions allow students to explore authentic scenarios, bridging the gap between theoretical knowledge and practical application. Advanced technologies, including OpenAI and Unreal Engine, provide personalized learning experiences that adapt to individual styles and paces, improving the quality and efficiency of education.

The scalability and adaptability of the virtual educational room underline their global potential. By tailoring these environments to the specific needs of various laboratories and institutions, this technology can democratize access to high-quality education, promote collaboration, and facilitate knowledge exchange across diverse communities. Such advancements have the potential to reshape the educational landscape by enabling more equitable and effective learning opportunities (Tastan & Tong, 2023).

5.2. Limitations of HydroVerse Immersive Virtual Classroom Environments

Despite their potential, HydroVerse Immersive Virtual Classroom Environments face several challenges that must be addressed to fully realize their capabilities. A significant limitation lies in the technical and logistical requirements for creating and maintaining high-fidelity virtual environments (Al-Jundi et al., 2022). These systems often rely on advanced hardware, substantial computational resources, and specialized technical expertise, which can limit accessibility for educational institutions with constrained budgets or resources (Tlili et al., 2021). Additionally, disparities in access to necessary hardware and reliable internet connectivity pose critical challenges, potentially exacerbating existing educational inequalities (Graves et al., 2021). Ensuring inclusivity for diverse learning styles and varying levels of technological proficiency further complicates the development and deployment of these systems (Sharma, 2024).

Moreover, while digital avatars enable engaging and dynamic interactions, they lack the nuanced human qualities—such as empathy, motivation, and inspiration—that traditional instructors provide (Oliveira et al., 2024). This raises important questions about the pedagogical effectiveness of artificial instructors compared to their human counterparts. Striking a balance between technological innovation and human interaction is crucial to maximizing the educational benefits of these systems (Dhanasekaran, 2025). Overcoming these challenges will require continuous development, thorough evaluation, and iterative refinement to ensure that virtual environments enhance rather than replace traditional educational approaches (Dritsas et al., 2025).

6. Conclusion and Future Work

This paper has presented the development and implementation of the HydroVerse Virtual Classroom, an innovative platform designed to transform the educational landscape in hydroinformatics. Built with Unreal Engine and experienced through Meta Quest 3, the system integrates advanced technologies such as extended reality, artificial intelligence, and natural language processing to provide a dynamic and interactive learning environment. Core components include the immersive XR classroom, a web-based presentation portal for content delivery, and an instructor collaboration panel that enables real-time oversight and mentorship. At the center is a novel adaptive virtual presenter, combining OpenAI's large language models with realistic Metahuman avatars, which delivers lectures, moderates discussions, and responds to learner questions with lifelike interaction. Together, these elements create a highly accessible, engaging, and personalized learning experience that addresses limitations of traditional methods while supporting global collaboration and inclusivity.

The HydroVerse Virtual Classroom significantly contributes to hydroinformatics education by enabling students to explore complex concepts through realistic simulations, interactive 3D media, and AI-guided instruction. Its adaptability and integration of artificial instructors demonstrate the potential for technology-driven innovation to enhance engagement, improve accessibility, and foster deeper understanding across diverse educational settings. Looking forward, several opportunities exist for extending this work. Key priorities include optimizing performance on standalone XR devices, ensuring the pedagogical accuracy of AI responses, and developing multi-user functionality for collaborative learning. Future research should also explore the role of adaptive features, such as learner feedback and emotion recognition, in refining personalization, as well as expanding the system's application beyond hydroinformatics into other disciplines. Advances in avatar realism, integration of mixed reality, and incorporation of domain-specific knowledge bases hold further promise for enriching learner interaction. By addressing these challenges, the HydroVerse Virtual Classroom can evolve into a robust, scalable, and inclusive educational framework that redefines immersive teaching and learning in a technology-driven world.

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8. Disclaimer

Mention of any brand name in no way implies recommendation of a particular manufacturer or product.

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