VR Math Bridge: Bridging Interactivity in Online Education with AI and VR

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***Abstract*—We present VR Math Bridge, a virtual reality (VR)-based application designed to enhance calculus education by combining immersive virtual environments with artificial intelligence (AI)-driven teaching assistance. VR Math Bridge creates a virtual classroom where students interact with Khan Academy videos and a 3D AI assistant that provides real-time, personalized feedback to their questions. This system leverages a floating panel for chapter selection, a virtual blackboard for video playback, and Cognitive 3D for analyzing user engagement. To demonstrate the system's capabilities, we developed a prototype on Quest 3, focusing on derivatives as the initial test topic. We conducted a preliminary subjective evaluation (n=2) of the prototype to collect early insights for future user study evaluation.**

***Index Terms*—AI-driven Education, Immersive Learning, Mathematics Education, Virtual Reality, Avatar, Embodied Agent**

I. Introduction

Mathematics is the universal language that serves as the foundation of science, technology, engineering, and mathematics (STEM) education. Numerous studies on mathematics education indicate that higher-level mathematics poses significant challenges for university students [1]–[5]. The rapid transition to online learning during the COVID-19 pandemic profoundly impacted global educational practices and significantly increased the use of online learning platforms [6]. On the other hand, average math scores fell below prepandemic averages, at least in the US [7], and their recovery has been very slow. While a study [8] suggests that platforms like Khan Academy[1] are as effective as traditional methods for first-year university mathematics education, online learning still faces challenges such as reduced engagement and feelings of isolation [9]. Enhancing student engagement—through interactive elements, for instance, has been identified as a key factor in improving both participation and performance [10]. Virtual reality (VR) and artificial intelligence (AI) have emerged as powerful tools in education, offering new possibilities for immersive and personalized learning. VR enables students to engage with content in an interactive immersive environment [11], while AI provides real-time feedback and adapts to individual learning needs [12]. Despite their significant potential, the application of VR and AI in mathematics education remains limited [13], [14]. Research that combines these two technologies for advancing university mathematics education is even scarcer. To address these challenges faced by online learning platforms and fill the research gap in integrating VR and AI within university mathematics education, we propose a VR-based application that extends the educational content of online platforms and incorporates an interactive AI character. As illustrated in Figure 1, VR Math Bridge creates a virtual classroom environment featuring a virtual blackboard displays educational content from online platforms. An AI-driven teaching assistant interacts with students overcoming the lack of interactivity in traditional online platforms. This assistant provides personalized support and answers questions, aiming to boost student engagement and improve learning outcomes. To achieve this, the system integrates Cognitive 3D,[2] a commercial platform for spatial analytics and user behavior tracking. By monitoring metrics such as video watch time and interaction duration with the AI assistant, VR Math Bridge ensures that the proposed features encourage meaningful interactions and maintain student focus, enhancing both engagement and learning effectiveness.

II. Related Work

A. VR-Based Mathematics Learning Systems

Several studies highlight the advantages of VR in mathematics education. Su et al. [15] developed a VR-based geometry learning system to teach concepts such as volume calculation and centroid derivation. Their research demonstrated significant improvements in students' learning outcomes and motivation compared to traditional teaching methods, with higher technological acceptance among learners. Similarly, Simonetti et al. [16] proposed a VR-based system that uses 3D visualization of mathematical functions to enhance conceptual understanding and interest in mathematics. Cheong et al. [17] explored VR-enhanced methods for teaching multivariable calculus, emphasizing the visualization of partial derivatives. Their findings showed that VR significantly improved students' understanding of derivative trends, particularly benefiting low-performing students.

However, Kang et al. [18] observed that while VR tools enhanced learning experiences, test scores for students using VR were lower than those in traditional classroom settings. They attributed this to inconsistencies in the VR materials and insufficient study time, highlighting the importance of

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

[2] https://cognitive3d.com

Fig. 1. The left image shows a user operating the Quest 3, while the right image displays the first-person view in VR Math Bridge, featuring the AI assistant and a virtual blackboard.

using unified and well-designed content. Building on these findings, our system integrates educational materials from Khan Academy to ensure uniformity and reliability as it was evaluated as the best option.

B. AI-Driven Learning Support

AI-driven systems have shown great promise in providing personalized and adaptive learning support. Qawaqneh et al. [19] proposed an AI-based virtual mathematics laboratory model, which significantly improved the motivation and engagement of middle-school students compared to traditional methods and 3D imaging-based laboratories. Sajja et al. [20] introduced an AI-enabled intelligent assistant framework that integrates dynamic flashcards, automated assessments, and content summarization through natural language processing. While the system is yet to be validated in real-world scenarios, its features demonstrate the potential of AI in higher education. Drawing from these ideas, our system incorporates an AI-driven 3D teaching assistant to provide real-time, personalized feedback and support.

C. Balancing Complexity and Engagement in Educational Tools

While advanced technologies can enhance learning, excessive complexity may hinder usability and effectiveness. Chatain et al. [21] investigated different levels of embodied interaction in mathematics education, concluding that simpler, more intuitive designs lead to better usability and learning outcomes. They emphasized the importance of balancing complexity and user experience in educational tools. This shaped our decision to simplify the content delivery within VR Math Bridge by using pre-existing educational resources, such as videos from Khan Academy, as a unified knowledge base. Kizilcec et al. [22] introduced the "Image Principle" in video instruction, showing that incorporating the instructor's face can enhance social presence and engagement. However, excessive visual stimuli may increase cognitive load, particularly if not personalized to individual learners' preferences. Building on this, our system employs a 3D AI-driven teaching assistant to provide a human-like presence, fostering engagement while minimizing unnecessary distractions.

III. System Implementation

We built a VR application using Unity[3] (2022.3.53f1). The application runs on a Quest 3[4] headset tethered via a USB cable to a Windows 11 PC with at least 8 GB of RAM and 4 GB of free storage. An internet connection is needed for cloud-based features, including AI interaction (via OpenAI API) and analytics (via Cognitive 3D). The main components of the system are: 1) virtual classroom, 2) large language model (LLM)-based avatar, and 3) user behavior analytics. The overall system architecture is shown in Figure 2, outlining the user interaction flow and core modules of VR Math Bridge.

A. Virtual Classroom Design

The virtual classroom replicates the traditional learning environment complete with desks and blackboard while leveraging VR to enhance interactivity and immersion. A floating panel enables students to select chapters and access supplementary materials. The virtual blackboard streams educational content, aligned with widely recognized calculus resources, as limited visual tools and differing VR systems prevent consistent materials for experimental and control groups. The avatar provides verbal explanations of the educational content while referencing materials displayed on the blackboard. Currently, the blackboard is used primarily for streaming Khan Academy videos and presenting instructional content. Future versions of the platform aim to expand the functionality of the floating panel, enabling learners to practice what they have learned by, for example, virtually drawing mathematical formulas using a controller or VR stylus. The AI avatar could then recognize these handwritten formulas displayed on the floating panel and provide real-time feedback, further enhancing interactivity and personalization in the learning experience.

[3]https://unity.com
[4]https://www.meta.com/jp/quest/quest-3

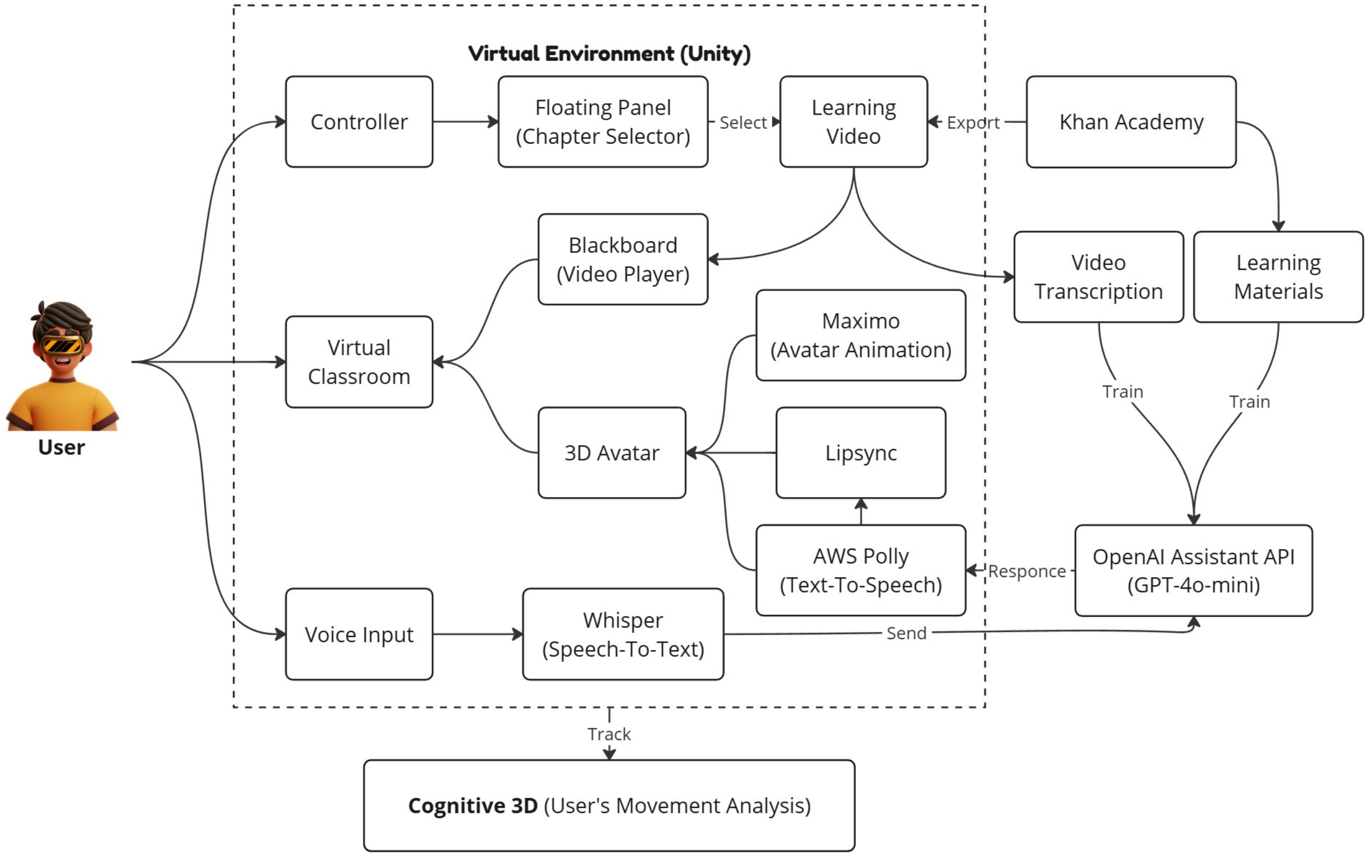

Fig. 2. System architecture of VR Math Bridge. The user interacts with the virtual environment via a controller and voice input. The virtual classroom includes a floating panel for chapter selection, a blackboard for video playback, and a 3D AI-driven avatar for real-time interaction. The AI assistant, powered by OpenAI API, provides personalized feedback using transcribed video content and educational materials from Khan Academy. Cognitive 3D tracks user movement and engagement for analysis, while animation and speech tools like Mixamo, AWS Polly, and Lipsync enhance the avatar's naturalness.

This modular design enables easy updates or replacements of virtual classroom components, allowing the system to adapt to emerging educational needs. For example, the streaming video module on the virtual blackboard can be updated by educators to cover new topics, such as replacing derivative-focused content with integral topics or other STEM-related materials. Similarly, the floating panel module can be reconfigured to display updated chapter selections and supplementary resources. Additionally, the AI assistant can be fine-tuned or re-trained to align with new content, ensuring it continues to provide accurate and contextually relevant feedback content. This flexibility ensures the system remains up-to-date with curriculum requirements while maintaining consistency across the learning environment. The immersive VR setting further encourages deeper engagement, mimicking real-world classroom dynamics while providing the adaptability of 3D-based online learning.

B. AI-Driven Virtual Assistant

In addition to the virtual classroom, VR Math Bridge provides a virtual avatar as an embodied teaching assistant that provides real-time, personalized guidance to enhance the learning experience. The avatar is powered by OpenAI GPT-4o-mini[5] and trained on Khan Academy's calculus curriculum,[6] the assistant responds to student queries with detailed explanations that supplement the video content and transcripts. This adaptive system dynamically adjusts its guidance in real-time based on each student's progress, providing personalized educational support.

To foster immersive interaction, the assistant incorporates natural gestures, facial expressions, and precise lip-sync animations. Rendered using Ready Player Me[7] and enhanced by the Lipsync SDK,[8] and Mixamo[9] animations, the assistant creates a human-like presence in the virtual classroom, making interactions feel natural, engaging and relatable.

Speech-to-text (STT) and text-to-speech (TTS) technologies further enhance communication between students and the assistant. We use WhisperSpeech[10] for STT to transcribe spoken queries into text for AI processing. For TTS, we implement

[5] https://platform.openai.com/docs/models/gpt-4o-mini
[6] https://www.khanacademy.org/math/calculus-1
[7] https://readyplayer.me/
[8] https://developers.meta.com/horizon/documentation/unity/audio-ovrlipsync-unity/
[9] https://www.mixamo.com/
[10] https://github.com/WhisperSpeech/WhisperSpeech

AWS Polly[11] to generate natural, human-like audio responses. For example, when a student asks, "*Can you explain the chain rule?*"[12] the assistant delivers a clear and concise explanation in audible speech. Simultaneously, the spoken text is displayed in a floating chatbox, providing a visual reference for the conversation.

C. User Behavior Analytics

We use Cognitive 3D[13] to gather insights into engagement and learning behaviors. The system monitors metrics such as time spent on the virtual blackboard, duration of AI assistant interactions, and user movement within the virtual classroom. Additionally, it supports advanced features like gaze tracking and Scene Explorer, which provides a playback of user movement and interaction behaviors within the environment.

In our study, we focus on two key metrics: video watch time on the virtual blackboard and interaction duration with the AI assistant. These provide critical insights into how students allocate attention across learning tools.

Cognitive 3D integrates into Unity via its SDK.[14] The system provides a comprehensive dashboard for data analysis, including project overviews, app performance metrics, and live operation monitoring. Additional features and metrics are available, as detailed in the official documentation.[15] These analytics, visualized through the Cognitive 3D dashboard (Figure 5), help refine the system and tailor content to students' needs.

IV. User Experience

VR and AI provide opportunities to address challenges in university mathematics education, such as improving social presence and engagement in remote learning environments and offering personalized support to cater to individual student needs. To demonstrate the potential of VR Math Bridge, we present a use case that illustrates its practical application in a calculus learning scenario. As shown in Figure 3, users enter a virtual classroom and interact with videos and topics through a floating panel. In this scenario, a student puts on the Quest 3 headset and opens VR Math Bridge, entering a virtual classroom designed for studying calculus concepts. As the video progresses, the student has the flexibility to pause at any point to review specific sections or clarify doubts by asking the AI-driven avatar for explanations or additional guidance. When difficulties arise in understanding a specific part of the video, such as the explanation of the chain rule, the AI assistant can be consulted directly by voice input using the microphone of the HMD (e.g., Quest 3). The AI assistant is exclusively voice-based, allowing users to interact naturally without the need for text input or a virtual human interface. Figure 4 shows the 3D AI assistant in the virtual classroom. The AI assistant uses STT to process the question and TTS to provide a response. The response is generated based on a transcription of the video content, including relevant materials from sources, which are pre-fed into the OpenAI model. The system tracks the student's movements, such as the duration of focus on the video or time spent interacting with the AI assistant, using Cognitive 3D.This use case demonstrates how VR Math Bridge integrates video-based learning, personalized AI assistance through an embodied digital human, and interaction tracking to address common challenges in online mathematics education. By allowing students to learn at their own pace while receiving natural, real-time support, VR Math Bridge aims to enhance engagement with and understanding of basic calculus topics.

V. Discussion

A. Observations and Challenges

We collected prelimary feedback on the prototype from two participants: a first-year college student and a graduate student. This small-scale pilot study was designed to identify initial usability issues and evaluate system feasibility. We acknowledge that two participants are insufficient to draw any conclusions. Future work will involve a user study evaluation with more participants. Additionally, no formal learning outcome data

[11]https://aws.amazon.com/polly/
[12]https://en.wikipedia.org/wiki/Chain_rule
[13]https://cognitive3d.com/
[14]https://cognitive3d.com/product/unity/
[15]https://docs.cognitive3d.com/

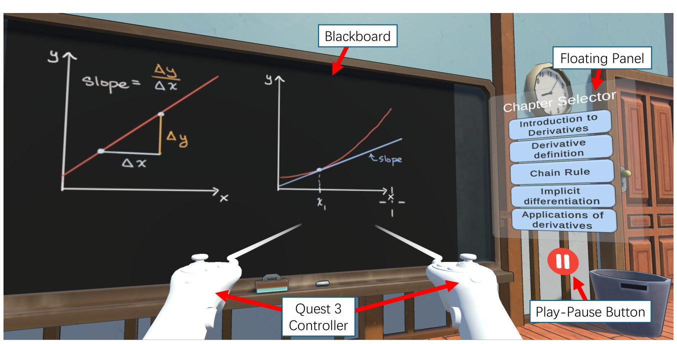

Fig. 3. The virtual classroom environment in VR Math Bridge. Users interact with a floating panel to select topics or materials, while the virtual blackboard streams videos aligned with the lesson.

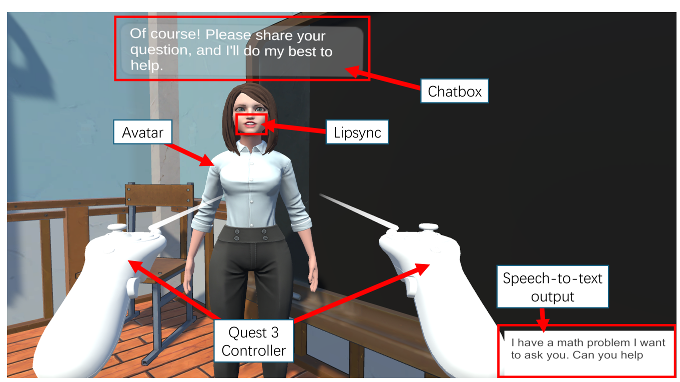

Fig. 4. The 3D AI virtual assistant in the VR classroom. Pressing the A-button on the Oculus controller allows the assistant to listen to user queries, transcribe them with Whisper, and respond using the OpenAI API. Responses are delivered through speech and displayed on a floating chatbox. The virtual assistant looks in the same direction of the user's movements, while simple gestures and animations make interactions appear natural and immersive.

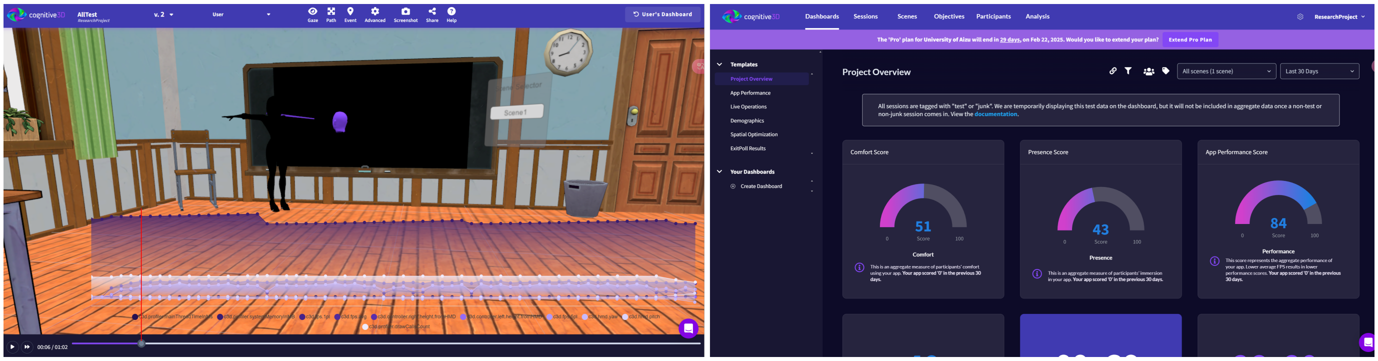

Fig. 5. Cognitive 3D in action. The left image shows the Scene Explorer, replaying user movement and interactions within the virtual classroom. The right image displays the dashboard, providing project overviews, app performance metrics, and behavior insights.

(e.g., pre and post tests or performance scores) were collected. The primary focus was on early system feasibility and user interaction. The first-year student had limited mathematical experience, while the graduate student had a stronger foundation in mathematics. Participants particularly valued the ability to select chapters based on their individual progress and appreciated the seamless integration of the AI assistant, which effectively addressed their queries and enhanced the learning experience.

However, five challenges were identified during testing. One major limitation was the inability to adjust video playback speed. This restriction, primarily caused by the delay in AI responses due to synchronization issues with the API, resulted in lengthening study sessions by approximately 5–10 minutes. Participants also mentioned that they felt tired and lost focus when asked to watch the video content in the VR environment, often mentioning "losing focus" after about three minutes of watching the instructional content. Another limitation was the lack of advanced tools for interactive mathematical visualization. While the current system ensures consistency with existing educational resources, it does not yet offer interactive 3D content tailored to specific calculus topics. Addressing this gap is a significant challenge but remains a priority for future development. AI response delays caused by the OpenAI API's response time also affected the user experience. Each interaction typically experienced a delay of approximately 3–4 seconds. Although the AI assistant provided accurate and relevant feedback, these delays disrupted the natural flow of interaction, emphasizing the need for optimization to improve responsiveness. Finally, fatigue emerged as a notable concern. Extended periods in the VR environment, particularly for watching videos on complex topics, led to disengagement and decreased focus. The primary cause of fatigue is the prolonged viewing of fixed content in VR. This underscores the importance of designing VR experiences that balance engagement with user comfort.

B. *Future Improvements and Directions*

To improve usability, upcoming version includes basic navigation features such as forward/backward buttons and video time display. We also aim to address the cognitive fatigue issue reported by participants to support personalized learning. Future development will also prioritize comprehensive user studies with more participants to evaluate the system's effectiveness. These studies will include formal pre-test and post-test evaluations, comparing traditional online video-based learning, VR-based video learning, and hybrid VR-AI learning. The hybrid approach refers to the integration of virtual reality's immersive environment with AI-driven personalized assistance. In this setup, students engage with educational content in a VR classroom while receiving real-time feedback and guidance from an AI teaching assistant, creating a combination of immersive interaction and adaptive learning. Data collection will encompass subjective feedback through Likert-scale surveys, measuring dimensions such as engagement, perceived usefulness, ease of use, and objective performance metrics, such as test scores on the learning topic (e.g., differential equations).

Future work will actively integrate interactive and unified visualization tools, such as CalcFlow[16] and CalcVR.[17] These tools will be manually designed and developed with careful reference to video content and curriculum materials, ensuring consistency across the teaching framework. Immersive 3D visualizations can create engaging and cohesive learning experiences for mathematical topics like vector fields or differential equations. Another development involves creating multi-user virtual classrooms to facilitate collaborative learning, where students can interact with peers and the AI assistant. By combining peer engagement with individualized support, the system can replicate the advantages of traditional classroom settings while leveraging the immersive capabilities of VR. Lastly, enhancing system usability remains a key focus. Future optimizations will aim to improve AI response times and introduce features such as adjustable video playback speeds to deliver a smoother and more engaging user experience. By addressing these limitations, the system will be refined and expanded to cover additional STEM disciplines, enhancing its effectiveness across diverse learning scenarios and positioning VR Math Bridge as a versatile educational tool.

[16]https://github.com/matryx/calcflow
[17]https://calcvr.org

VI. Conclusion

We presented VR Math Bridge, a VR-based application designed to enhance university mathematics education by integrating AI-driven assistance and VR technologies. The system combines immersive learning environments with personalized AI feedback, enabling students to engage with calculus concepts through video-based content and interactive support. Despite its potential, the system currently faces challenges such as the inability to adjust video playback speed, limited visualization tools, and occasional delays in AI responses. These factors highlight areas for improvement to better meet user needs and further reduce cognitive load in the VR learning environment. Moving forward, we aim to enhance the system by integrating advanced visualization tools, exploring multi-user virtual classrooms, and conducting comprehensive user studies. These studies will compare learning outcomes between traditional online platforms, VR-based applications, and hybrid VR-AI solutions, providing valuable insights into the system's effectiveness. By addressing these challenges and expanding the system's capabilities, VR Math Bridge represents a significant step toward transforming mathematics education, leveraging the unique advantages of VR and AI to create more engaging, personalized, and effective learning experiences.

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