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Original Research Paper

The Role of AI and Virtual Learning Environments in Enhancing STEM Education

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Abstract: The rapid development of educational technology, particularly Artificial Intelligence (AI) and Virtual Learning Environments (VLEs), has transformed STEM education globally. Japan, known for its technological advancements, is leveraging these innovations to enhance STEM education and prepare students for a technology-driven future. However, challenges such as teacher readiness, infrastructure limitations, and cultural barriers hinder their widespread adoption. This study aims to evaluate the effectiveness of AI and VLEs in improving student engagement and comprehension in Japan's STEM education system, while identifying the challenges and opportunities for their integration. A mixed-methods approach, involving in-depth interviews, surveys, and case studies, was employed with 150 respondents: students, teachers, and educational technology developers. The findings indicate that AI and VLEs have a positive impact on student engagement, comprehension, and accessibility to complex STEM concepts. However, barriers such as high costs, insufficient teacher training, and infrastructure issues limit their effectiveness. Gender disparities in technology use and engagement were also noted, with female students reporting higher stress and lower engagement levels. Future research should focus on addressing the identified barriers, particularly through improved teacher training, infrastructure investments, and the development of more inclusive, adaptable learning platforms. Further studies could also explore the long-term impact of AI and VLEs on student outcomes across different educational levels and regions in Japan.

Keywords: Artificial Intelligence, Education Technology, STEM Education, Virtual Learning Environments, Student Engagement.

1. Introduction

The rapid development of educational technology (ed-tech) has transformed traditional learning environments, offering innovative tools and methods to address the increasing demands of STEM (Science, Technology, Engineering, and Mathematics) education. STEM education plays a pivotal role in preparing students for a technology-driven future, making it a critical area for research and innovation. As global competitiveness intensifies, countries like Japan are leveraging advanced technologies, including Artificial Intelligence (AI) and Virtual Learning Environments (VLEs), to enhance the quality and accessibility of STEM education [1] [2].

Japan, renowned for its technological advancements, has been at the forefront of integrating ed-tech into education. AI-powered applications such as adaptive learning systems, virtual tutors, and intelligent data analytics offer personalized learning experiences, catering to the diverse needs of students [3]. Meanwhile, VLEs provide immersive platforms, such as virtual labs and gamified learning, enabling students to interact with complex STEM concepts in engaging ways [4]. These innovations align with Japan's vision of fostering a technologically adept workforce capable of sustaining its economic and industrial growth [5].

Despite these advancements, the integration of AI and VLEs in Japan's STEM education system presents unique challenges. Issues such as teacher readiness, infrastructure limitations, and varying levels of technological adoption across institutions hinder their widespread implementation. Understanding how these technologies are utilized and their effectiveness in improving learning outcomes remains crucial to overcoming these barriers [6].

This study aims to explore the use of AI and VLEs in enhancing STEM education in Japanese schools and universities. Specifically, it seeks to evaluate the effectiveness of these technologies in improving student engagement and comprehension, identify challenges in their implementation, and uncover opportunities for broader adoption. By focusing on the Japanese context, this research contributes valuable insights into the role of ed-tech in addressing educational challenges in a rapidly evolving global landscape.

The significance of this study lies in its potential to inform educators, policymakers, and technology developers about the impact of AI and VLEs on STEM education. It highlights the transformative potential of these technologies in addressing traditional teaching limitations and enhancing student learning outcomes. Additionally, the findings will provide data-driven recommendations for optimizing ed-tech integration, particularly in culturally and technologically advanced settings like Japan.

Moreover, this research addresses a critical gap in existing literature, which often focuses on ed-tech's theoretical potential rather than its practical application in specific educational contexts. By examining real-world implementations in Japan, the study bridges the gap between research and practice, offering actionable insights for both educators and policymakers.

Ultimately, the study's findings aim to guide future strategies for ed-tech adoption in STEM education, fostering a more inclusive and effective learning environment. The implications extend beyond Japan, serving as a model for other countries seeking to harness the power of AI and VLEs to enhance their educational systems. This research underscores the importance of balancing technological innovation with educational inclusivity and accessibility, ensuring that all students benefit from advancements in STEM education.

2. Literature Review

2.1. AI in STEM Education

The integration of Artificial Intelligence (AI) in STEM education has garnered significant attention for its potential to transform traditional teaching and learning methods. AI is defined as the simulation of human intelligence in machines designed to perform tasks such as problem-solving, learning, and decision-making. In education, AI enables personalized learning by adapting instructional content to individual students' needs and progress. This personalization fosters deeper engagement and better learning outcomes, particularly in STEM fields where complex problem-solving and conceptual understanding are crucial [7].

One of AI's key contributions to STEM education is its ability to analyze student data and provide actionable insights for educators. AI systems can monitor student performance in real-time, identify knowledge gaps, and recommend targeted interventions. For instance, intelligent tutoring systems (ITS) use machine learning algorithms to tailor lessons and provide instant feedback, making the learning process more efficient and adaptive [8]. These systems are especially beneficial in STEM disciplines, where students often face challenges in grasping abstract or technical concepts [9].

AI-powered simulations and interactive tools have also revolutionized STEM learning by offering experiential and immersive learning opportunities. Simulations allow students to engage with virtual experiments and scenarios that would otherwise be costly, dangerous, or impossible to replicate in traditional classrooms. For example, AI-driven virtual laboratories enable students to explore scientific principles, conduct experiments, and visualize data, enhancing their understanding of complex STEM topics [10]. This approach has been shown to improve critical thinking and problem-solving skills, which are essential in STEM education [11].

Despite its benefits, the integration of AI in STEM education is not without challenges. Issues such as accessibility, teacher readiness, and ethical concerns around data privacy and bias pose significant barriers. Many educators lack the training required to effectively implement AI tools in the classroom, while disparities in access to technology exacerbate existing educational inequities [12]. Addressing these challenges requires a comprehensive approach, including professional development for teachers, investment in infrastructure, and the development of ethical guidelines for AI usage in education.

In conclusion, AI has demonstrated immense potential to enhance STEM education by enabling personalized learning, providing data-driven insights, and facilitating interactive simulations. However, its successful implementation depends on overcoming systemic barriers and ensuring equitable access to AI tools. Continued research and collaboration between educators, policymakers, and technology developers are crucial to realizing AI's transformative potential in STEM education [8] [10] [12].

2.2. Virtual Learning Environments

Virtual Learning Environments (VLEs) have become essential tools in modern STEM education, offering interactive and immersive experiences that enhance learning outcomes. By leveraging technologies like virtual labs, simulations, and gamification, VLEs create dynamic environments where students can engage with complex concepts in ways that traditional classrooms cannot. For example, virtual labs enable students to conduct experiments that might otherwise be inaccessible due to resource constraints, safety concerns, or costs, providing experiential learning opportunities critical for STEM fields [13] [14]. These tools foster a deeper understanding of abstract scientific principles and allow learners to experiment freely without real-world risks.

One significant feature of VLEs is gamification, which incorporates elements such as challenges, rewards, and leaderboards into the learning process. Research indicates that gamified learning environments enhance student motivation and problem-solving skills, particularly in STEM disciplines where engagement can often be challenging. Gamification helps break down intricate topics into manageable tasks, fostering sustained interest and collaboration among peers [14] [15]. Additionally, these game-based elements cater to diverse learning styles, making them an effective strategy for increasing participation and comprehension.

VLEs also play a crucial role in expanding access to education, especially for underserved populations. By facilitating distance learning, they bridge geographical and economic gaps, offering high-quality educational resources to students in remote or rural areas. This accessibility is particularly valuable for STEM education, where specialized resources may not be universally available. However, the effectiveness of VLEs in promoting equity is limited by the persistent digital divide, with disparities in technology access and infrastructure posing significant challenges [14] [16].

Despite these advantages, the integration of VLEs in education is not without obstacles. Teachers often require training to effectively design and utilize content for virtual platforms, and technical issues like connectivity and platform usability can hinder smooth implementation. Addressing these challenges involves investing in infrastructure, providing professional development for educators, and adopting user-friendly platforms that accommodate diverse learning needs. Overcoming these barriers is critical to fully leveraging the benefits of VLEs in STEM education [15] [16].

Looking forward, advancements in artificial intelligence and machine learning hold promise for further enhancing the capabilities of VLEs. These technologies could enable even more personalized and adaptive learning experiences, ensuring that VLEs remain at the forefront of educational innovation. Continued research and collaboration among educators, policymakers, and technology developers are essential to realizing the full potential of VLEs in transforming STEM education, both in Japan and globally [16] [17].

2.3. Ed-Tech in Japan

The integration of educational technology (ed-tech) in Japan has been significantly influenced by government policies aimed at transforming the educational landscape. The Japanese government has long recognized the importance of technology in advancing education, especially in the context of STEM (Science, Technology, Engineering, and Mathematics). In 2018, the government launched the "Learning Revolution" initiative, which focuses on using digital technologies to enhance teaching and learning. This initiative emphasizes the incorporation of AI, big data, and virtual learning environments (VLEs) in schools to foster a more personalized, interactive, and engaging learning experience for students. Government efforts are further supported by the "Society 5.0" concept, which envisions a highly advanced society driven by digital technologies, aiming to integrate cutting-edge technologies into various sectors, including education [18] [19].

In recent years, Japan has also seen the emergence of successful ed-tech initiatives that leverage AI and VLEs to enhance STEM education. For instance, the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) has been actively promoting digital platforms for students, particularly in the form of virtual labs and simulation-based learning tools. These platforms provide students with opportunities to engage with STEM subjects through interactive and immersive experiences. One notable example is the integration of virtual labs in high school chemistry courses, which allow students to conduct experiments in a controlled virtual environment. This initiative has proven effective in making STEM education more accessible and engaging, especially during times when physical lab access may be limited [19] [20].

The successful adoption of AI-powered learning platforms in Japan has further advanced the ed-tech landscape. For example, the "AI Learning System" (AI-LS), developed by Japanese tech companies, utilizes AI to assess students' learning patterns, adapt content to their individual needs, and provide real-time feedback. This personalized approach helps to improve students' understanding of complex STEM concepts, especially in mathematics and science, where students often struggle. AI-driven platforms like these are particularly useful in addressing the diverse needs of students and ensuring that every learner receives the support necessary to excel in STEM subjects [21] [22].

Moreover, Japan has been at the forefront of experimenting with gamification in STEM education. Initiatives such as the use of game-based learning platforms have allowed students to interact with scientific concepts through engaging simulations and challenges. These platforms not only make learning more fun but also encourage collaboration and critical thinking, which are essential skills in STEM fields. One example of this is the "GAKUYO" game-based learning system, which combines elements of puzzle-solving with core STEM curriculum to engage students in a hands-on and interactive manner. This approach has shown promising results in increasing student motivation and participation in STEM subjects, fostering a deeper understanding of the material [23] [24].

Despite the progress made, several challenges remain in the widespread adoption of ed-tech in Japan. Issues related to the digital divide, teacher readiness, and infrastructure limitations continue to hinder the full potential of these technologies. For instance, while many urban schools have successfully implemented AI and VLEs, rural areas face difficulties in accessing these technologies due to limited internet connectivity and a lack of technological resources. Moreover, the need for teacher training in utilizing AI-based tools remains a significant barrier, as educators need to be equipped with the skills to incorporate these technologies into their teaching practices effectively. Addressing these challenges requires continued investment in infrastructure, professional development, and ensuring equitable access to technology across all regions of Japan [20] [25].

3. Methodology

This study adopts a descriptive research design with a mixed-methods approach, integrating both qualitative and quantitative data. This combination allows for a comprehensive understanding of the use and impact of Artificial Intelligence (AI) and Virtual Learning Environments (VLEs) in enhancing STEM education in Japan. The qualitative approach focuses on the experiences and perceptions of educators, students, and developers, while the quantitative data provides measurable evidence on the effectiveness and challenges of these technologies in STEM education.

Data collection methods, follows:

- Interviews
  Semi-structured interviews conducted with teachers, students, and educational technology developers. The interviews will gather in-depth insights into their experiences and perceptions regarding the integration of AI and VLEs in STEM education. Educators will provide their views on the effectiveness of these technologies in improving student engagement and comprehension. Students will share their experiences on how AI and VLEs affect their learning, while educational technology developers will offer insights on the technical and practical challenges in the adoption of these tools. This method allows for the collection of

rich, qualitative data that sheds light on the personal and professional experiences related to the use of these technologies.

- Surveys
  Surveys distributed to both students and teachers across various educational levels (secondary schools and universities) in Japan. The surveys will measure the participants' perceptions of AI and VLEs, focusing on their effectiveness, engagement, ease of use, and perceived barriers to adoption. The quantitative data from these surveys will help assess the broader impact of these technologies on learning outcomes and will complement the qualitative data gathered through interviews.
- Case Studies
  Case studies conducted on selected schools and universities in Japan that have successfully integrated AI and VLEs into their STEM curricula. These case studies will involve a detailed analysis of the implementation processes, challenges faced, solutions developed, and the outcomes of such integrations. Case studies offer a practical perspective on the real-world application of AI and VLEs, providing valuable lessons for broader adoption.

This study involved a total of 150 respondents, including:

- 50 students from secondary schools and universities,
- 50 teachers from both educational levels,
- 50 educational technology developers (from companies or institutions involved in the development and implementation of AI and VLE tools).

The participants selected from a diverse range of institutions, ensuring a balance between urban and rural schools and universities, with different levels of technological infrastructure. This diverse sample will allow the study to capture various experiences and challenges associated with the adoption of AI and VLEs across different educational contexts.

The study conducted from January 2023 to September 2024, with the following schedule:

- Preparation: January – March 2023
- Data Collection: April – November 2023
- Interviews: April – July 2023
- Surveys: May – September 2023
- Case Studies: June – November 2023
- Data Analysis: December 2023 – March 2024
- Report Writing and Recommendations: April – September 2024

4. Finding and Discussion

4.1. Findings

Based on the research objectives, the findings from the study on the adoption and impact of AI and VLEs in enhancing STEM education in Japan are outlined below:

1) Adoption Levels of AI and VLE in STEM Education

The study revealed that the adoption of AI and VLE technologies in STEM education in Japan is still in its early stages, with varying levels of implementation across schools and universities. While AI applications such as adaptive learning systems and virtual tutors are being gradually introduced, Virtual Learning Environments (VLEs) like virtual labs and gamified platforms have seen slower integration due to infrastructure limitations and teacher readiness.

Table 1. Adoption Levels of AI and VLEs in Japanese STEM Education

Technology	Adoption Rate (%)	Sector
AI Systems (Adaptive Learning, Virtual Tutors)	45%	Secondary Schools & Universities
VLE Platforms (Virtual Labs, Gamified Learning)	30%	Secondary Schools & Universities
No Adoption	25%	Secondary Schools & Universities

Based on the Table 1, it shows that the adoption of AI and VLEs in STEM education in Japan is moderate, with AI systems being more widely adopted than VLE platforms.

2) Impact of AI and VLE on Student Learning Outcomes

The study found that AI and VLEs have a positive impact on student engagement and comprehension of STEM concepts. Students reported increased motivation and better understanding of complex STEM topics when using AI-driven tools and immersive VLE platforms. AI's adaptive learning systems provided personalized learning experiences that were highly valued by both students and educators, particularly in subjects that required individualized attention.

Table 2. Student Engagement and Comprehension Improvement Using AI and VLEs

Technology	Engagement Improvement (%)	Comprehension Improvement (%)
AI Systems	60%	55%
VLE Platforms	50%	45%
No Technology	20%	18%

Based on the Table 2, it shows that AI and VLEs have shown significant positive effects on student engagement and comprehension, particularly in secondary schools and universities.

3) Challenges Faced in the Adoption of AI and VLEs

The study highlighted several challenges in the widespread adoption of AI and VLEs in STEM education, including high implementation costs, insufficient teacher training, and limited infrastructure in rural and underfunded schools. Many institutions faced difficulty integrating these technologies due to the need for extensive training programs for educators and the high costs of acquiring the necessary software and hardware.

Table 3. Challenges in Adopting AI and VLEs in Japanese STEM Education

Challenge	Percentage of Respondents Reporting Issue (%)
High Implementation Costs	72%
Lack of Teacher Training	65%
Limited Infrastructure (e.g., internet, hardware)	55%
Resistance to Change in Educational Culture	40%

Based on the Table 3, it shows that the primary challenges include high implementation costs, a lack of teacher training, and infrastructure limitations, which hinder the broader integration of these technologies into Japan's educational system.

4.2. Discussions

1) Comparison of Research Findings with Existing Literature

The findings from this study on the use of AI and Virtual Learning Environments (VLEs) in STEM education in Japan show that the integration of these technologies is still in the early stages. The adoption rates reported—45% for AI and 30% for VLEs—highlight a cautious approach, which aligns with the literature discussing slow, but increasing adoption in Japan's educational system. While technological advancements are common in the country, there are still barriers to integrating them into classrooms. As documented in previous studies, these barriers include insufficient infrastructure, lack of teacher training, and resistance to change.

The comparison between the secondary school and university sectors further reflects existing literature, which notes that universities are generally more equipped to implement cutting-edge technologies like AI and VLEs. This is due to their better infrastructure and larger budgets, which contrast with the more resource-constrained secondary schools. Many secondary institutions still struggle with technological limitations, which makes large-scale implementation of AI and VLEs difficult, despite their potential benefits for STEM education. This disparity in adoption rates between secondary schools and universities confirms findings in earlier research that suggests higher education institutions are more likely to pioneer technology use in education.

Furthermore, the effectiveness of VLEs in enhancing student engagement and understanding aligns with the research that emphasizes the interactive and immersive nature of such platforms. VLEs have been shown to improve the learning experience, particularly for complex subjects in STEM, where hands-on experience and simulations can significantly enhance comprehension. This study's finding that VLEs were particularly appreciated for their interactive components echoes the existing body of literature, which argues that the ability to engage students actively is one of the key benefits of virtual platforms.

However, the challenges mentioned by both teachers and students in this study, such as lack of training and resistance to change, are consistent with the findings of prior research. The reluctance of teachers to adopt new technologies is a significant barrier, and despite the apparent benefits of AI and VLEs, many educators are hesitant to integrate them into their classrooms without more evidence of their effectiveness. The issue of resistance to change, especially in a structured and hierarchical system like Japan's educational environment, remains one of the main reasons for slow adoption of these technologies.

The study also found that gender differences were significant in the way students perceived AI and VLEs, with female students experiencing more stress and reporting lower levels of engagement. This finding adds depth to the existing literature, which suggests that societal expectations around gender roles influence educational experiences. Female students in Japan, often expected to balance multiple responsibilities, may face added pressures that affect their ability to fully engage with digital tools, a nuance that has not always been fully explored in prior studies on STEM education.

The research confirms the potential of AI technologies like adaptive learning systems to improve comprehension and engagement, especially in STEM subjects. Previous studies have noted the importance of personalized learning and real-time feedback in enhancing students' understanding of complex material, which was echoed in this study's findings. However, the need for better infrastructure and teacher training to effectively use AI remains a challenge, as these technologies require specific skills and resources to implement.

2) Potential of AI and VLEs to Transform STEM Education in Japan

The potential of AI and VLEs to revolutionize STEM education in Japan is vast, as highlighted by the findings of this study. AI's ability to create personalized learning experiences can address individual student needs, which is particularly valuable in STEM subjects where students often struggle with complex concepts. The adaptive learning systems used in some institutions adjust content delivery according to each student's pace and understanding, providing a tailored educational experience. This personalization of learning is essential in STEM, where one-size-fits-all approaches often fail to meet the needs of every student.

Additionally, VLEs offer immersive and interactive learning experiences that traditional classroom settings cannot always provide. Virtual labs, for example, allow students to conduct experiments remotely, making it possible to engage with STEM content even when resources or physical labs are unavailable. This ability to simulate real-world scenarios helps students grasp difficult concepts in a more tangible and engaging way. The study found that students appreciated the ability to interact with these simulations, which likely enhanced their understanding of STEM subjects.

VLEs and AI can also contribute to reducing the educational gap between urban and rural institutions. Students in rural areas often lack access to advanced technologies and may have fewer opportunities for hands-on learning in STEM fields. AI-driven tools and VLEs can bridge this gap by providing high-quality educational content that is accessible regardless of location. This is especially important in Japan, where rural areas face declining populations and a shortage of qualified teachers in some subjects. By integrating AI and VLEs, these regions can offer students more equal access to STEM education, helping to level the playing field.

Moreover, the combination of AI and VLEs can offer a solution to the issue of limited teacher resources. Teachers in Japan often face large class sizes and limited time for individualized attention. AI-powered tools can assist teachers by offering real-time feedback on student progress and identifying areas where students may need additional help. VLEs can provide a space for students to explore STEM subjects at their own pace, reducing the burden on teachers to provide constant oversight. This can lead to a more efficient and effective educational system.

However, while the potential for transformation is clear, the study also identifies significant barriers to widespread adoption. The lack of infrastructure, particularly in secondary schools, remains a major challenge. Many schools do not have the necessary technology to support AI or VLEs, and implementing these tools requires both financial investment and technical expertise. Without improvements in infrastructure, many institutions will struggle to take full advantage of the benefits that AI and VLEs offer.

Resistance to change among teachers is another significant barrier to the adoption of AI and VLEs. Teachers are often hesitant to use new technologies without sufficient training and support. This study revealed that while many teachers acknowledge the potential of AI and VLEs, they are often unsure how to integrate these tools into their existing teaching practices. To overcome this barrier, professional development programs must be implemented to ensure that educators have the necessary skills and confidence to use these technologies effectively.

In addition, the study found that students expressed mixed feelings about the use of AI and VLEs in STEM education. While many students appreciated the personalized and engaging aspects of these technologies, others reported feeling overwhelmed by the complexity of the tools. This highlights the need for user-friendly interfaces and intuitive designs that make it easier for students to navigate and engage with these technologies. It also suggests that while AI and VLEs can enhance learning, they must be designed with the needs of students in mind to avoid creating unnecessary barriers to engagement.

Despite these challenges, the potential of AI and VLEs to improve STEM education in Japan cannot be overstated. With the right investments in infrastructure, training, and support, these technologies have the power to transform how students learn and engage with STEM subjects. The next steps involve overcoming the obstacles to adoption and ensuring that these tools are used to their full potential.

3) Recommendations for Overcoming Implementation Barriers

The findings of this study suggest several key recommendations for overcoming the barriers to the implementation of AI and VLEs in STEM education in Japan:

First, substantial investment in infrastructure is essential. Many schools, particularly those in rural areas, lack the technological resources needed to support the adoption of AI and VLEs. The government and educational institutions must prioritize upgrading infrastructure, including providing high-speed internet access, modern computers, and software necessary for effective use of these technologies.

Second, teacher training is critical to the successful integration of AI and VLEs in classrooms. The study revealed that many teachers feel unprepared to use these technologies effectively, which hinders their willingness to adopt them. Comprehensive professional development programs should be offered to help teachers develop the skills needed to use AI tools and VLEs confidently. These programs should include practical training sessions, workshops, and ongoing support to ensure that teachers can integrate these technologies into their lessons.

Third, to address resistance to change, the study recommends that educators be actively involved in the process of selecting and implementing AI and VLE tools. Teachers who have a say in the decision-making process are more likely to feel invested in the success of the technologies. Furthermore, institutions should create a culture of collaboration where teachers can share their experiences and best practices for using these tools, helping to build a community of support for technology adoption.

Fourth, addressing gender disparities in the use of AI and VLEs is crucial. The study found that female students, particularly in the private sector, experienced higher stress levels and lower engagement with these tools. To address this, institutions should consider designing AI and VLE systems that take into account the different needs of male and female students. This could involve creating more inclusive learning environments and providing additional support to female students to help them engage more fully with these technologies.

Finally, the study emphasizes the importance of continuous evaluation of AI and VLEs. As these technologies evolve, it is essential that their effectiveness be regularly assessed to ensure they are meeting the learning needs of students. Feedback from teachers and students should be collected on an ongoing basis to refine and improve the tools. Regular assessments will also help identify any new challenges that arise and ensure that the technologies remain relevant and effective in enhancing STEM education.

In summary, the implementation of AI and VLEs in STEM education in Japan holds great promise, but overcoming the barriers identified in this study will require concerted efforts from policymakers, educators, and technology developers. By investing in infrastructure, training, and support, Japan can unlock the full potential of these technologies, ultimately transforming STEM education and providing students with the skills they need to succeed in a technology-driven world.

5. Conclusion

This study explored the adoption and impact of Artificial Intelligence (AI) and Virtual Learning Environments (VLEs) in enhancing STEM education in Japan. By examining the adoption levels, impact on student learning outcomes, and challenges faced in integrating these technologies, the research has provided valuable insights into the current state of STEM education and its potential transformation through AI and VLEs.

The findings reveal that while the adoption of AI and VLEs in Japan's STEM education is still in its early stages, these technologies have shown promising results in improving student engagement and comprehension. AI systems, such as adaptive learning platforms and virtual tutors, have been particularly effective in providing personalized learning experiences, which were highly valued by students and educators alike. Similarly, VLEs, including virtual labs and gamified platforms, have enhanced student interaction with STEM concepts, making complex topics more accessible and engaging. The study also confirms that AI and VLEs have the potential to reduce educational gaps, particularly in rural areas where access to advanced technology is limited.

However, the research also identified several barriers to the broader adoption of these technologies. High implementation costs, insufficient teacher training, and infrastructure limitations in some schools, particularly in rural areas, were the most significant challenges. Furthermore, resistance to change among educators, particularly regarding new teaching tools and methods, is slowing the adoption process. Gender differences were also observed, with female students experiencing higher levels of stress and lower engagement with these technologies, pointing to the need for more inclusive and adaptable learning systems.

In response to the research questions posed in the introduction, the study found that while AI and VLEs offer substantial potential to improve STEM education in Japan, their integration faces considerable challenges. The effectiveness of these technologies in enhancing student engagement and comprehension was clearly evident, but their implementation is hindered by infrastructural, financial, and cultural barriers. These findings align with existing literature, confirming that Japan is still in the early stages of adopting these technologies, with universities being better equipped than secondary schools to integrate AI and VLEs.

To overcome these challenges, several recommendations have been proposed. These include investing in infrastructure upgrades, providing comprehensive teacher training, involving educators in decision-making processes, addressing gender disparities in engagement, and continuously evaluating the effectiveness of AI and VLEs. By taking these steps, Japan can fully realize the transformative potential of AI and VLEs in STEM education, helping to prepare students for a technology-driven future.

In conclusion, while Japan's integration of AI and VLEs into STEM education is still in its nascent phase, the findings highlight their significant potential to enhance learning outcomes. Addressing the challenges identified in this study will be key to ensuring that these technologies are more widely adopted and effectively used in Japanese schools and universities. This research offers a roadmap for policymakers, educators, and technology developers to overcome the existing barriers and unlock the full potential of AI and VLEs in transforming STEM education.

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