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A Model for Implementing the Metaverse in Science Education in Lower Secondary Schools in Tehran

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A B S T R A C T

Purpose: This study aims to design and implement a model for integrating metaverse technology into science education within lower secondary schools in Tehran.

Methodology: A mixed-methods approach was employed, combining qualitative and quantitative research methods. In the qualitative phase, semi-structured interviews were conducted with 12 educational experts, and data were analyzed using open, axial, and selective coding. In the quantitative phase, a researcher-made questionnaire was distributed to 256 teachers and administrators from lower secondary schools in Tehran. The data were analyzed using descriptive statistics and structural equation modeling (SEM) to validate the proposed model.

Findings: The study identified five main categories influencing the implementation of the metaverse in education: causal factors, intervening factors, contextual factors, strategies, and expected outcomes. Intervening factors, such as control and supervision and access to technology, were found to be particularly critical. The study also highlighted the importance of technological infrastructure and supportive policies as contextual factors. The proposed model demonstrated a good fit with the data, indicating that metaverse integration could enhance student engagement, motivation, and academic performance when implemented with careful consideration of the identified factors.

Conclusion: The integration of metaverse technology in science education holds significant potential for transforming traditional teaching methods. However, its successful implementation requires addressing key challenges related to technological infrastructure, regulatory frameworks, and financial feasibility. The study provides a valuable framework for guiding the adoption of metaverse technologies in educational settings, emphasizing the need for ongoing research and policy development to support this innovative approach.

Keywords: *Metaverse, Science Education, Lower Secondary Schools, Educational Technology, Student Engagement.*

1. Introduction

The rapid evolution of digital technologies has revolutionized various sectors, including education (Omale, 2024; Öztop et al., 2024; Yee Ching et al., 2024). Among the emerging technologies, the metaverse—a collective virtual shared space, created by the convergence of virtually enhanced physical reality and physically persistent virtual reality—has garnered significant attention for its potential to transform educational environments. The metaverse is not merely a futuristic concept but an increasingly tangible reality that promises to redefine how educational content is delivered, experienced, and assessed (Suh & Ahn, 2022). The metaverse offers an immersive, interactive, and personalized learning environment that transcends the limitations of traditional classrooms. As highlighted by Chamola (2023), the metaverse can facilitate learner-centered constructivist education by enabling students to engage in interactive and experiential learning experiences that are difficult to replicate in physical classrooms (Chamola, 2023). This immersive environment allows for the simulation of complex concepts, fostering a deeper understanding and retention of knowledge. For instance, Celik (2023) demonstrated that metaverse-based learning significantly enhances vocabulary retention in language learning, which is indicative of the broader potential of the metaverse in other educational contexts (Celik, 2023).

Incorporating the metaverse into education is not without its challenges. One of the primary concerns is the digital divide, which refers to the gap between those who have access to modern information and communication technology (ICT) and those who do not. This divide can exacerbate educational inequalities, particularly in regions where access to the necessary technological infrastructure is limited (Al-Zubair, 2021). Furthermore, as Ahmadon (2023) notes, the successful integration of the metaverse into education requires not only technological infrastructure but also the development of appropriate pedagogical strategies that leverage the unique affordances of this new medium (Ahmadon, 2023).

The metaverse also poses challenges related to privacy, security, and ethical considerations. As highlighted by Catagua (2023), the metaverse introduces new risks in terms of data privacy and cybersecurity, which are particularly concerning in educational contexts where the protection of minors is paramount (Catagua, 2023). The potential for data breaches and the misuse of personal information in these virtual environments underscores the need for robust security protocols and regulations. Additionally, the ethical implications of using avatars and virtual identities in the metaverse must be carefully considered, as they can influence how individuals interact and perceive each other in these digital spaces (Akbari et al., 2023).

Despite these challenges, the potential benefits of the metaverse in education are profound. As discussed by Aldweesh (2023), the metaverse can create a fusion of physical and virtual learning environments, providing students with opportunities to explore and engage with content in ways that are not possible in traditional settings (Aldweesh, 2023). This fusion can lead to more inclusive and equitable education, as it allows for the customization of learning experiences to meet the diverse needs of students. For example, Bernaschina (2023) proposed an inclusive metaverse model for media arts education, which aims to cater to students with different learning abilities and needs, thus promoting equity and inclusion in the educational process (Bernaschina, 2023).

The concept of the metaverse is also being explored in specialized fields of education. For instance, in medical education, the metaverse has the potential to revolutionize how complex procedures and surgeries are taught and practiced. Hulsen (2023) discusses the applications of the metaverse in medicine and healthcare, emphasizing how it can enhance training and education for medical professionals by providing realistic simulations of medical procedures (Hulsen, 2023). This approach not only improves the practical skills of medical students but also reduces the risks associated with practicing on real patients.

In addition to its applications in specialized fields, the metaverse can also support the development of critical skills that are essential for success in the 21st century. As noted by Dreamson and Park (2023), metaverse-based learning environments can promote the development of problem-solving and critical thinking skills by placing students in scenarios where they must navigate complex challenges and make decisions in real time (Dreamson & Park, 2023). This experiential learning approach is particularly effective in preparing students for the demands of the modern workforce, where these skills are increasingly valued.

The integration of the metaverse into education is also aligned with the broader trend of digital transformation in various sectors. As argued by Giovanni (2023), the metaverse represents a key component of the transition to Industry 5.0, which emphasizes the integration of human creativity and technological innovation. In this context, the

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metaverse can be seen as a platform that not only enhances educational outcomes but also prepares students for the future workforce by familiarizing them with the tools and technologies that will dominate the next industrial revolution (Giovanni, 2023).

The role of educators in the metaverse is another critical factor to consider. As noted by Agrati (2023), the success of metaverse-based education depends significantly on how educators adapt to this new medium. Teachers must not only be proficient in using metaverse technologies but also be able to design and implement effective instructional strategies that leverage the unique affordances of the metaverse. This requires ongoing professional development and support, as well as a willingness to experiment with new pedagogical approaches (Agrati, 2023).

Moreover, the metaverse can also serve as a platform for fostering collaboration and community building among students. Aşıksoy (2023) highlighted the potential of the metaverse to create a sense of presence and community among learners, which is crucial for fostering engagement and motivation. In a metaverse-based classroom, students can collaborate on projects, participate in discussions, and engage in social interactions that mirror those in a physical classroom, thereby enhancing their overall learning experience (Aşıksoy, 2023).

The implementation of the metaverse in education also raises important questions about the future of traditional educational institutions. As suggested by Laurens-Arredondo (2023), the rise of metaversities—virtual universities that exist entirely within the metaverse—could challenge the traditional model of higher education. These metaversities offer flexible, accessible, and personalized learning experiences that can cater to a global student population, potentially disrupting the traditional university model (Laurens-Arredondo, 2023).

In conclusion, the metaverse presents a transformative opportunity for education, offering new ways to engage students, personalize learning, and prepare them for the future workforce. However, the successful implementation of the metaverse in education requires careful consideration of the challenges related to access, privacy, security, and pedagogy. As the technology continues to evolve, it is essential for educators, policymakers, and researchers to collaborate in developing frameworks and strategies that maximize the benefits of the metaverse while mitigating its risks. By doing so, the metaverse can fulfill its potential as a powerful tool for enhancing education in the digital age. Therefore, this study aims explore the implementation of the metaverse in science education in lower secondary schools.

2. Methods and Materials

2.1. Study Design and Participants

This study employed a mixed-methods design, grounded in both interpretive and positivist paradigms. In the qualitative phase, the research was exploratory, aimed at identifying relevant indicators and proposing a new theoretical framework for implementing the metaverse in science education. The quantitative phase, on the other hand, was descriptive, focusing on validating the relationships identified in the qualitative phase. The study is classified as applied research due to its focus on developing a conceptual framework and also as developmental research due to the generation of knowledge through the design of a final model that incorporates both local and international indicators while examining the effects of the variables under investigation. An inductive approach was used in the qualitative phase, as the research sought to identify the key factors influencing the metaverse in the studied population. Data were gathered from two primary sources: secondary data from books, articles, and documents, and primary data obtained through interviews. Thus, the study falls under the category of both field and library research.

The study's qualitative phase involved expert participants, including key informants with experience in science education and management within lower secondary schools in Tehran. These experts were selected based on specific criteria, such as a minimum of five years of managerial experience in schools, familiarity with key concepts related to the research topic, and experience with school-related technologies. The sample size for the qualitative phase was determined through theoretical saturation, which was achieved after conducting semi-structured interviews with 12 participants. Additional interviews were conducted to ensure saturation, but further interviews were deemed unnecessary after consultation with advisors, confirming that theoretical saturation had been reached.

For the quantitative phase, the study population included all teachers and principals from lower secondary schools in Tehran during the 2023-2024 academic year, totaling 850 individuals. A sample size of 265 was determined based on the Morgan table, with an additional 10% selected to ensure generalizability and account for potential attrition. A total of 256 valid and complete questionnaires were obtained for

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analysis. The sampling method for the qualitative phase was purposive, using snowball sampling to identify and select experts. For the quantitative phase, stratified random sampling was used, with participants selected proportionally based on their roles as teachers or principals.

2.2. Data Collection

Data collection for this study involved both qualitative and quantitative tools. In the qualitative phase, semi-structured interviews were conducted with key experts in the field. These interviews were designed to identify the factors influencing the implementation of the metaverse in science education. The interviews were guided by a protocol developed according to standard methodologies, with the questions designed to explore various dimensions such as contextual factors, intervening variables, and strategies for implementing the metaverse. The interview process was dynamic, with questions evolving to maintain the interview's focus and achieve the study's objectives. Each interview lasted approximately 60 minutes, and the interviews were transcribed and coded for analysis. Additionally, a thorough literature review was conducted to identify existing trends, challenges, and gaps in the current research.

In the quantitative phase, a researcher-made questionnaire was developed based on the indicators identified in the qualitative phase. This questionnaire consisted of two parts: demographic information and 43 Likert-scale items, designed to assess the key factors identified in the qualitative analysis. The questionnaire was distributed among the selected sample, and the responses were collected for further analysis. The questionnaire's validity and reliability were assessed using structural equation modeling and Cronbach's alpha, respectively. Validity was also confirmed through the consultation with 10 experts in the field, using the Content Validity Ratio (CVR). The reliability of the qualitative data was further ensured through Cohen's kappa coefficient, which demonstrated a substantial agreement between coders.

2.3. Data Analysis

Data analysis was conducted in two phases corresponding to the qualitative and quantitative components of the study. In the qualitative phase, data from the interviews were analyzed using open, axial, and selective coding, following the Strauss and Corbin model. The software MAXQDA was employed to facilitate the coding process and to help in organizing and analyzing the qualitative data. The grounded theory approach was used to develop a conceptual framework that accurately reflected the insights gained from the interviews.

For the quantitative phase, descriptive statistics were used initially to summarize the demographic characteristics of the respondents and to analyze their responses to the questionnaire items. Frequencies, means, and medians were calculated to provide a basic overview of the data. The primary focus of the quantitative analysis was to evaluate the model fit using structural equation modeling (SEM) with AMOS software. Various fit indices, including RMSEA, GFI, and CFI, were used to assess the model's adequacy. Additionally, the relationships between variables were examined to confirm the validity and reliability of the identified factors and the overall model. The analysis confirmed that the proposed model had a good fit, supporting the findings from the qualitative phase and providing a comprehensive understanding of the factors influencing the implementation of the metaverse in science education in lower secondary schools in Tehran.

3. Findings and Results

In the qualitative phase of the study, which involved 12 experts, the demographic characteristics revealed a diverse group of participants. Regarding their professional roles, 50% were assistant principals, 33% were in management positions, and 17% were experts. The participants' work experience varied, with 25% having 5 to 10 years of experience, 50% with 10 to 15 years, and another 25% with over 15 years of experience. Gender distribution was equal, with 50% of the participants being male and 50% female. Age-wise, 41% of the participants were over 46 years old, 25% were between 36 to 45 years old, and 34% were under 35 years old. In terms of educational qualifications, 42% held a master’s degree, while 58% had a doctoral degree, reflecting a highly educated group contributing to the study.

The findings of this study are presented through the analysis of qualitative and quantitative data. In the qualitative phase, open coding was utilized to identify relevant concepts, followed by axial coding to extract core categories, and finally, selective coding was used to systematically relate the central phenomenon to other categories. This process not only validated the relationships between categories but also identified areas needing further development, resulting in the creation of a hypothetical qualitative model. The axial coding process, supported by expert feedback and revisions, led to the identification of

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five main categories deemed significant in the context of metaverse implementation in schools. These categories, along with their associated components, are presented in Table 1.

Table 1

Selective Coding Results

Code	Main Categories	Core Categories
Level of media literacy in society	Media literacy and awareness	Causal factors
Parental awareness of the technology		
Level of technology used in schools	Technological maturity	
Student awareness		
Technological maturity of schools		
Acceptance of technology by colleagues and teachers		
School technological infrastructure	Technology and content	
Content produced at the metaverse level		
Economic feasibility of using the metaverse	Financial justification	
Integration capability of existing technologies in schools	Synchronization and personalization	
Synchronization of metaverse content with textbook content		
Attractive and personalized course content design		
Ministry's support for metaverse development	Supportive policies	Contextual factors (Background)
School management's support for technology implementation		
Social support for new technologies		
National policies on school technology		
Technological infrastructure in society	Technological infrastructure	
Internet speed and availability in society		
Security and privacy in the metaverse	Safety and privacy	
Protection of privacy in the metaverse		
Evaluation and monitoring capabilities in the metaverse	Control and supervision	Intervening factors
Control and management of metaverse content		
Content capabilities for assessing academic progress		
Technology access for teachers	Access and management	
Time management capabilities in the metaverse		
Legal aspects and regulations for metaverse use	Laws and regulations	
Standardization of produced content	Content standardization	
Participation in content production and dissemination	Content interaction	
Development of interactive education strategies in the metaverse	Interaction and participation strategy	Strategies
Collaborative content production in the metaverse		
Enhancing IT skills in schools	Skill strategy	
Synchronization and integration of online and offline teaching technologies	Synchronization strategy	
Cost reduction and increased access to infrastructure	Cost reduction strategy	
Improving academic performance	Academic performance outcomes	Outcomes
Enhancing the level of learning		
Increasing student creativity		
Improving learning experience		
Increasing student motivation	Motivational-participatory outcomes	
Enhancing student participation		
Personalizing education based on student needs		
Reducing educational costs	Organizational performance outcomes	
Improving teacher-student-parent communication		
Enhancing evaluation and monitoring systems		

The quantitative findings are summarized in descriptive statistics, which are presented in Table 2. These statistics highlight the central tendencies and variability of the identified categories.

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Table 2

Descriptive Statistics of Research Variables

Variable	Mean	Standard Deviation	Variance	Kurtosis	Skewness
Causal Factors	4.156	1.281	1.559	0.161	0.319
Intervening Factors	4.234	1.087	1.110	0.161	0.319
Contextual Factors	3.245	1.425	1.122	0.161	0.319
Strategies	3.145	1.632	1.425	0.452	0.236
Outcomes	3.652	1.456	1.236	0.452	0.456

The highest mean score was observed in the "Intervening Factors" category, while the "Strategies" category had the lowest mean score. In terms of kurtosis and skewness, all variables were within the normal range, indicating a normal distribution of the data.

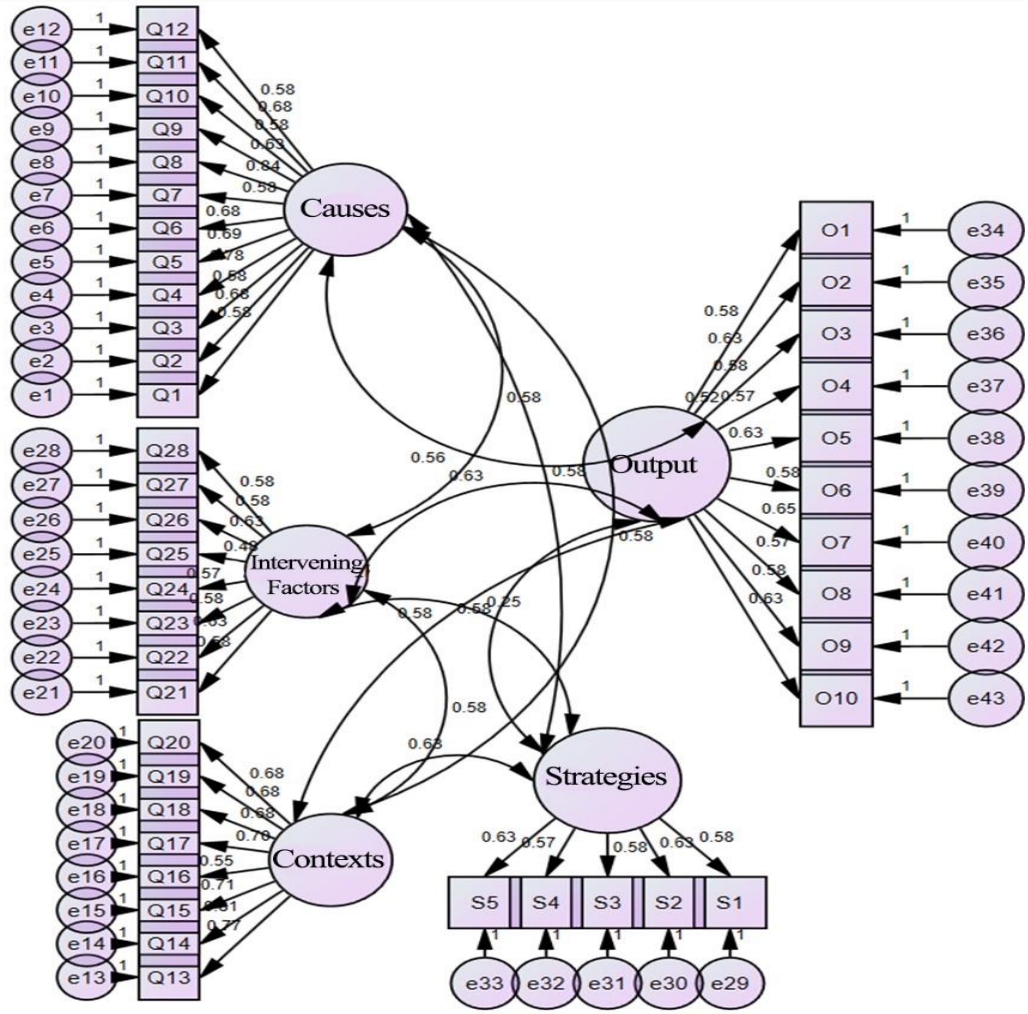
Table 3

Overall Measurement Model Fit Indices for the Metaverse in Schools

RMSEA	TLI	CFI	AGFI	GFI	Chi-square/df
0.075	0.965	0.979	0.872	0.930	2.167

Figure 1

Final Structural Model with Standard Coefficients



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As shown in Table 3 and Figure 1, all factor loadings for the categories were above 0.50, and the p-values were below 0.05, indicating that the categories significantly and meaningfully contribute to the measurement model. The model fit indices were also within acceptable ranges, with RMSEA at 0.075, chi-square/df at 2.167, and other indices (CFI, GFI, TLI, AGFI) all exceeding their respective thresholds. Therefore, the measurement model of the metaverse and its outcomes is confirmed to have a good fit with the research data, validating the model's structure and relationships.

4. Discussion and Conclusion

The current study aimed to explore the implementation of the metaverse in science education within lower secondary schools in Tehran, identifying the key factors that influence its successful integration. The findings revealed a multifaceted framework composed of five main categories: causal factors, intervening factors, contextual factors, strategies, and expected outcomes. These elements were synthesized into a comprehensive model that can guide the implementation of metaverse technology in educational settings.

The results of the study indicated that among the identified categories, intervening factors such as control and supervision, access to technology, and legal regulations were particularly influential in the successful adoption of the metaverse in education. This aligns with findings from previous research, which emphasize the importance of regulatory frameworks and technological accessibility in the adoption of new digital technologies in educational contexts (Awan, 2023). Specifically, the need for robust control mechanisms and management tools to monitor and guide students' activities in the metaverse was highlighted as crucial, reflecting concerns raised by Catagua (2023) regarding privacy and security in virtual environments (Catagua, 2023).

The study also found that contextual factors, including technological infrastructure and supportive policies, play a significant role in the readiness of schools to adopt metaverse technologies. This is consistent with the work of Azoury and Hajj (2023), who underscored the necessity of a supportive infrastructure for the successful integration of the metaverse in education (Azoury & Hajj, 2023). In particular, the availability of high-speed internet and advanced digital tools within schools was identified as critical for enabling immersive and interactive learning experiences. This echoes the findings of Pregowska (2023), who noted that the lack of adequate infrastructure is one of the primary barriers to the effective use of the metaverse in higher education (Pregowska, 2023).

Moreover, the study's identification of financial justification as a critical causal factor is supported by prior research that highlights the economic challenges associated with implementing advanced technologies in educational settings. For example, Aljanabi (2023) discussed the high costs of developing and maintaining metaverse platforms, which can be prohibitive for many educational institutions (Aljanabi, 2023). The financial feasibility of metaverse integration is therefore a crucial consideration, particularly in resource-constrained environments where funding for educational technology is limited.

The strategic elements identified in the study, such as the development of skills, synchronization of online and offline learning, and cost reduction strategies, reflect the broader trends in educational technology adoption. The importance of skill development in utilizing metaverse tools was also noted by Agrati (2023), who emphasized the need for both teachers and students to be proficient in navigating these new digital environments (Agrati, 2023). Similarly, the synchronization of metaverse content with traditional curricula, as highlighted in this study, aligns with findings by Lee (2023), who stressed the importance of integrating new technologies with existing educational frameworks to ensure coherence and continuity in learning (Lee, 2023).

The study's findings regarding the expected outcomes of metaverse integration, such as improved academic performance and enhanced student motivation, are consistent with the positive impacts reported in previous research. For instance, Celik (2023) found that students engaged in metaverse-based learning demonstrated higher levels of engagement and retention compared to those in traditional learning environments (Celik, 2023). This suggests that the immersive nature of the metaverse can lead to more effective and meaningful learning experiences, a conclusion that is further supported by the work of Suh and Ahn (2022), who identified increased student motivation as a key benefit of learner-centered, constructivist approaches facilitated by the metaverse (Suh & Ahn, 2022).

However, the study also highlights several challenges associated with the implementation of the metaverse in education. The identification of security and privacy concerns as significant contextual factors resonates with the concerns raised by Tukur (2023), who emphasized the need for stringent security measures to protect users in virtual

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environments (Tukur, 2023). Additionally, the study's findings regarding the importance of legal regulations in governing the use of the metaverse in schools align with the perspectives of Akbari et al. (2023), who discussed the complexities of establishing legal frameworks for new digital technologies (Akbari et al., 2023).

One of the more novel findings of this study is the emphasis on the role of supportive policies at both the school and national levels in facilitating the adoption of the metaverse. This finding suggests that the success of metaverse integration in education is not solely dependent on technological factors but also on the broader policy environment. This is supported by the research of Laurens-Arredondo (2023), who argued that policy support is crucial for the widespread adoption of metaverse technologies in educational institutions (Laurens-Arredondo, 2023).

Despite the significant insights gained from this study, several limitations must be acknowledged. First, the study was conducted within a specific geographical and cultural context—lower secondary schools in Tehran—which may limit the generalizability of the findings to other regions or educational systems. The unique characteristics of the Iranian education system, including its technological infrastructure and policy environment, may influence the applicability of the results to different contexts. Moreover, the study's reliance on qualitative data from a relatively small sample of experts and practitioners may not fully capture the diversity of perspectives on metaverse integration in education. While the qualitative approach provided rich insights, the inclusion of a larger and more diverse sample could enhance the robustness of the findings. Additionally, the study focused primarily on the perspectives of educators and administrators, potentially overlooking the experiences and views of students, who are the primary users of metaverse technologies in educational settings. Finally, the rapid pace of technological advancements means that the findings of this study may become outdated as new metaverse technologies and applications emerge, necessitating ongoing research to keep up with these developments.

Future research should aim to address the limitations identified in this study by expanding the scope and scale of the investigation. Comparative studies across different cultural and educational contexts would provide valuable insights into how the metaverse can be effectively integrated into diverse educational systems. Additionally, future research should incorporate the perspectives of students, parents, and other stakeholders to gain a more comprehensive understanding of the challenges and opportunities associated with metaverse integration in education. Longitudinal studies could also be beneficial in assessing the long-term impacts of metaverse-based learning on student outcomes, such as academic performance, motivation, and social interaction. Furthermore, as new metaverse technologies continue to develop, there is a need for ongoing research to explore their potential applications in education and to evaluate the effectiveness of different metaverse-based teaching strategies. Finally, given the ethical and legal concerns identified in this study, future research should investigate the development of guidelines and frameworks to ensure the safe and responsible use of the metaverse in educational settings.

Based on the findings of this study, several practical recommendations can be made for educators, administrators, and policymakers interested in integrating the metaverse into educational settings. First, schools should prioritize the development of technological infrastructure, including high-speed internet and access to advanced digital tools, to support the effective use of metaverse technologies. Investment in professional development for teachers is also essential, ensuring that they have the skills and knowledge necessary to navigate and utilize metaverse platforms effectively (Agrati, 2023). Additionally, schools should consider implementing supportive policies at both the institutional and national levels to facilitate the adoption of the metaverse in education. This includes developing guidelines for the ethical and responsible use of metaverse technologies, as well as establishing legal frameworks to protect the privacy and security of users (Catagua, 2023). Moreover, schools should explore the potential of the metaverse to enhance student engagement and motivation by integrating immersive and interactive learning experiences into the curriculum. This could involve the development of metaverse-based projects and activities that align with existing educational goals and standards (Suh & Ahn, 2022). Finally, schools should consider the economic implications of metaverse integration, exploring cost-effective strategies for implementing these technologies in a way that is sustainable and accessible to all students, regardless of their socio-economic background (Aljanabi, 2023).

In conclusion, while the metaverse offers exciting possibilities for transforming education, its successful integration requires careful consideration of the technological, pedagogical, and ethical challenges involved. By addressing these challenges and leveraging the unique affordances of the metaverse, educators and policymakers

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can create more engaging, personalized, and effective learning environments that prepare students for the demands of the digital age. The findings of this study provide a valuable framework for guiding the implementation of metaverse technologies in education and highlight the need for continued research and collaboration to realize the full potential of the metaverse in shaping the future of learning.

Authors' Contributions

All authors significantly contributed to this study.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

In this study, to observe ethical considerations, participants were informed about the goals and importance of the research before the start of the interview and participated in the research with informed consent.

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