Guest Editorial
The Metaverse and the Future of Education

I. Introduction

THE metaverse is seen as an evolution paradigm of the next-generation Internet, able to support a diverse range of persistent and always-on interconnected synchronous multiuser virtual environments where people can engage with others in real time, merging the physical and virtual world [1], [2], [3]. The concept was first mentioned in 1992s Neal Stephenson novel "*Snow Crash*" [4], and it follows the web and mobile Internet revolutions, allowing users to experience virtual environments in an immersive and *hyperspatiotemporal* manner [1]. Thus, it represents a paradigm shift in digital interaction, enabling real-time, multidimensional experiences that transcend the boundaries of physical space with the promise of bringing new levels of social connection and collaboration. The metaverse exists within the Internet, but not in the traditional way of seeing the world through a screen [1]. Instead, the metaverse aims to provide immersive experiences based on the convergence of spatial computing technologies that enable multisensory user interactions [e.g., virtual reality (VR), augmented reality (AR), and mixed reality (MR)] [2], [3] combined with 3-D data and artificial intelligence. The metaverse is also related to the concept of digital twins (DTs), which are digital replicas of elements in the real world (e.g., assets and processes) that mirror and synchronize in real time with their source, creating a bidirectional connection between them. While DTs focus more on the bidirectional connection between real and virtual and the accuracy of the representation toward better decision-making, the metaverse looks at sociotechnical challenges of seamless embodied communication between users and the dynamic interactions with the virtual spaces.

Thus, the metaverse refers to multiple types of technology and a broad shift in how we interact with them. This includes scenarios such as healthcare, future workplaces, retail, enhanced entertainment and social media experiences, and education and their impact. Although the use of immersive technologies in education has been investigated for many years, the "*Education Metaverse,*" "*Edu-Metaverse,*" or "*Metaverse for Learning*" have recently increased the interest in the use of shared, persistent digital ecosystems where users can interact, socialize, create, and ultimately learn [5]. Corporations, capitals, and nongovernmental enterprises are driving the development of the metaverse and its use in various industry and social sectors. However, for the Edu-Metaverse, it is essential to consider critical challenges, such as how to design and use the *Edu-Metaverse* in teaching and learning effectively. This remains a crucial challenge for developing effective learning experiences that take advantage of the affordances of this medium. Other critical sociotechnical considerations include ethical and governance issues related to the metaverse and related technologies, including security, privacy, equity, accessibility, and intellectual property [6].

Thus, papers included in this special issue of the IEEE Transactions on Learning Technologies (TLT) discuss and share fundamental research outcomes and innovative application cases of the metaverse in education, showcasing the latest developments in this field toward addressing the challenges mentioned earlier while guiding future research directions.

II. Brief Literature Review of the *Edu-Metaverse* in TLT

TLT, sitting at the intersection of Computer Science and Learning Technology, has featured itself as a key venue for researchers and educators to disseminate cutting-edge research on emerging technologies for educational purposes. Prior to this special issue, TLT has already published several articles related to the *Edu-Metaverse*, paving the way for this special issue. For example, in [6], Wang et al. provided a deeper analysis of the *Edu-Metaverse*, outlining definitions, features, and related models of the *Edu-Metaverse*. They proposed an ecosystem for designers and educators to contemplate when designing and utilizing an *Edu-Metaverse* for teaching and learning, serving as a cornerstone for scholarly discussions that are reflected in this special issue.

Beck et al. [7] reviewed 47 existing studies on the *Edu-Metaverse*, providing a comprehensive overview of the diverse research themes over the past 20 years. The paper offers valuable insights into multiple aspects of the *Edu-Metaverse*, including its guiding theories and models, learning design, teaching strategies, assessment practices, and technical issues. The paper concludes with practical implications for researchers and practitioners in this field.

To explore the effectiveness of new technology in education, English as a second language education has been a constant use case, partially due to the large population of English learners across the globe, making it one of the largest educational markets. A timely publication in TLT is Wu et al. [8], which envisages the future of language education within the *Edu-Metaverse*. The authors explained the alignment of *Edu-Metaverse* features and fundamental language acquisition principles and provided examples of the current metaverse platforms for language education. In addition, Wu et al. [8] proposed a transdisciplinary framework for the *Edu-Metaverse* in language education by

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synthesizing related learning theories and models. The framework includes transdisciplinary, pedagogy, technology, actor, and learning aspects.

The three papers in TLT have shed some illuminating light on the future of the *Edu-Metaverse*. Based on them, the special issue aims to uncover more uncharted research topics within this new field of research.

III. Papers in This Special Issue

This special issue offers a comprehensive overview of its development, key themes, and emerging challenges, providing valuable insights into the state of *Edu-Metaverse* research. The papers presented here can be divided into four subtopics: 1) the current state of the metaverse for learning research; 2) the definition of the metaverse in education and frameworks grounded in pedagogical strategies tailored for this medium; 3) the design and evaluation of *Edu-Metaverse* applications; and 4) other sociotechnical considerations for the Edu-Metaverse.

A. Current State of the Metaverse for Learning Research

The current state of *Edu-Metaverse* research is characterized by an interdisciplinary field that draws upon computer science, education sciences, psychology, and human–computer interaction, among other areas. Researchers are exploring the potential of immersive and interconnected virtual environments to enhance educational experiences, offering interactive learning, collaboration, and simulation opportunities. For example, Chen et al. [A1] examine 310 academic papers published between 2004 and 2022, identifying key contributors, cooperative patterns, and research themes in this field. Their findings indicate that the *Edu-Metaverse* has increasingly gained academic attention since 2019. The research identifies eight main themes within the *Edu-Metaverse* field, including areas, such as metaverse-based physical education, collaborative problem-based learning in health/medical education, virtual learning environments for art education, science, technology, engineering, and mathematics (STEM) education through metaverse-enabled laboratories, language learning in immersive metaverse environments, supporting social communication skills in children with autism, gamified experience-based education in virtual worlds, and quantitative research on learners' experiences. In addition, the study highlights challenges and areas for further exploration in *Edu-Metaverse* research, including data security and privacy protection concerns, balancing real-world and virtual-world identities, preparing instructors for teaching, and assessing higher-order thinking skills in *Edu-Metaverse*-based problem-based learning.

Villalonga-Gómez et al. [A2] explore the application of the metaverse in higher education (HE). The authors conducted a systematic literature review of articles published since 2007, identifying 115 articles, with 34 related explicitly to the metaverse in HE. The analysis reveals a growing trend in using the educational metaverse, with a significant increase in publications in recent years examined from three dimensions: 1) technological; 2) pedagogical; and 3) content. Its main applications include second language learning and professional simulation, which are crucial in HE. These experiences generally yield positive results, attributed to the immersive nature of the metaverse and the active role of learners who take center stage, emphasizing the communicative and interactive opportunities that emerge within the educational context and the learning community.

B. Defining the Metaverse in Education and Frameworks Grounded in Pedagogical Principles

The definition of *Edu-Metaverse* is still evolving, quickly adapting advances in related technologies, and examining the implications and challenges in adopting those in educational settings. This evolution is reflected in a group of papers discussing this definition, grounding it to pedagogical principles and learning theories, and proposing frameworks to adapt it to real-life situations, considering technology affordances. For example, Sin et al. [A3] discuss the concept of an educational metaverse, proposing a constructivist metaverse learning theory with eight actionable principles to guide the development of the *Edu-Metaverse* and its applications. They suggest a framework for an *Edu-Metaverse*, connecting knowledge via knowledge graphs and VR to enhance learning through association, exploration, and engagement. They introduce a prototype and report positive results from testing it with students, highlighting its benefits in providing a focused and structured learning environment like a mind map.

Kim et al. [A4] identify two main challenges in developing practical educational applications for the metaverse: 1) the lack of theory-driven designs that align with established principles of how people learn and 2) the need for evaluation methods beyond usability to assess their impact on learning outcomes. The paper explores applying three learning theories—experiential learning theory, distributed cognition theory, and embodied learning theory—to design educational VR experiences. It suggests that these theories can inform the development of educational metaverse applications and enhance their ability to support learning. The authors introduce two science education VR environments created by the authors' lab, incorporating these theories into their design.

Han et al. [A5] highlight the challenge of preparing learners to fully engage with *Edu-Metaverse*-related technologies, mainly since there is a lack of studies on how to enhance learner engagement through human–machine collaboration within the *Edu-Metaverse*. The study proposes a framework to facilitate learner engagement with human–machine interactions to address this gap. The framework has two main components: 1) technology enhancement within *Edu-Metaverse* and 2) interactions among learners and avatars in *Edu-Metaverse* contexts. The authors suggest that learner engagement can occur in three patterns: 1) training engagement guided by the *Edu-Metaverse*; 2) collaboration engagement supported by the *Edu-Metaverse*; and 3) creative engagement empowered by the *Edu-Metaverse*. The study also conducts a case analysis to validate the proposed theoretical framework and engagement patterns.

Chen et al. [A6] highlight that although there is a growing interest in applying the metaverse to education, there is currently

no consensus on a technical *Edu-Metaverse* framework. The authors propose a five-layer framework supported by management and incentive mechanisms to address this challenge. In addition, they outline design criteria for three critical elements in the Edu-Metaverse: 1) virtual avatars; 2) virtual learning resources; and 3) virtual teaching scenarios, along with interaction modes. The authors develop a prototype system based on this framework and design criteria to demonstrate its feasibility and usability.

Zhang et al. [A7] discuss the emergence of the metaverse concept in technology and highlight the absence of authentic metaverse learning experiences in massive open online courses (MOOCs). The paper introduces a new framework called massive open metaverse courses (MOMCs) and the key technologies that enable immersive and three-dimensional learning experiences, addressing the current limitations of MOOCs. The authors then present a case study as an example of an MOMC environment enabled by volumetric video and VR and AR technologies. They describe how this course was developed and discuss the advantages of MOMCs over MOOCs and their current limitations.

C. *Design and Evaluation of* Edu-Metaverse *Applications*

Another group of papers focused on applications of the *Edu-Metaverse* to determine, among other factors, the effectiveness and appropriateness of metaverse educational settings. For example, Lee [A8] addresses the challenges that English as a foreign language students often face when learning a second language, particularly the lack of meaningful context, which can lead to demotivation. The study utilized a customizable metaverse platform to create an interactive scenario where students could engage with multimodal language input and missions for task-based problem-solving based on constructivist language learning principles. Their experiments showed how students actively engaged in the metaverse activity, collaboratively creating narratives through interaction, and producing narratives to solve the problem. The study suggests pedagogical implications for using the metaverse as a tool for second language learning based on the positive results observed in the study, highlighting how a metaverse-based approach can enhance language learning by providing a meaningful and engaging context for students.

Xie et al. [A9] discuss a pilot study that aims to understand the impact of immersive VR (IVR) technology on science education in secondary schools. To do so, they conducted a randomized controlled pilot trial in a secondary school to compare learning outcomes when using IVR compared to traditional video-viewing activities, showing significant differences in intrinsic learning motivation, academic self-efficacy, learner satisfaction, and academic achievement between the two activities, and discussing the reasons behind these findings and acknowledging the study's limitations.

Tian et al. [A10] highlight the challenges traditional Chinese Kung Fu enthusiasts face in learning and teaching martial arts offline due to the limitations of 2-D videos. To overcome these issues, the authors introduce the concept of the "Kung Fu Metaverse," a new training system that offers an avatar with various Chinese Kung Fu styles, allowing learners to observe postures and transitions from different angles. It also provides real-time feedback through a composite navigation module. Two experiments were conducted to assess the cognitive experience and the instructions' impact on the learning outcomes.

D. *Other Sociotechnical Considerations*

Analyzing the efficacy and regulatory impacts of metaverse-related technologies in an educational environment is essential. The world has been trying to bridge the *digital divide* in the past decades. Now, we are seeing the emergence of a new "Metaverse Divide" [6], i.e., disparities in access to resources experienced by individuals or groups, such as access to Internet connectivity and the necessary technological infrastructure to engage with and benefit from metaverse experiences fully, reflecting the broader digital inequalities prevalent in society. Researchers and policymakers increasingly recognize the importance of addressing these issues to ensure equitable access to the *Edu-Metaverse*'s educational, social, economic, and cultural opportunities in the contemporary digital landscape. For example, Zhai et al. [A11] highlight the growing importance of education equity as a global sustainable development goal and the interest it has generated among educators. It discusses the emergence of virtual teaching communities to reduce educational disparities by sharing resources and exchanging information. However, it emphasizes that achieving deep collaboration among individuals within these communities remains challenging. The authors suggest that the metaverse could be a potential solution to promote deep collaboration and communication among individuals. It notes that while the potential exists, the specific path to using the metaverse to enhance educational equity needs to be clarified. Therefore, the paper reviews using the *Edu-Metaverse* to support social interactions within virtual teaching communities.

Song et al. [A12] discuss the *Edu-Metaverse* challenges, including issues related to immersion, custom tools, instructional design, platform convenience, and ethical and privacy concerns. The study introduces an *Edu-Metaverse* teaching platform to promote cognitive engagement, combining rich social interactions among avatars, custom tools for user-generated content, and a user-friendly setup accessible on standard computers with webcams. A usability test was conducted in a designing interactive learning environments course, with results indicating that students positively perceived the platform's teaching, social, and cognitive aspects. The study concludes with discussions on design principles for educational metaverse platforms based on the findings and explores potential future work in this area.

IV. Conclusion

The *Edu-Metaverse* represents a dynamic and evolving field with numerous opportunities for research and innovation. Future research should be guided by a commitment to enhancing educational outcomes, fostering inclusivity, and addressing the unique challenges and ethical considerations associated with metaverse-related technologies. In addition, interdisciplinary collaboration between educators, technologists, social scientists, and policymakers is crucial for realizing the full potential of

the metaverse as a transformative tool for education. Essential aspects include the following.

1) Technological aspects include the design and development of immersive learning environments, infrastructure, interoperability and standards, security, and privacy.
2) Pedagogical frameworks tailored for the metaverse, considering design and evaluation of educational content (including user experience studies) and assessment to measure learning outcomes and inform instructional improvements.
3) Accessibility and inclusivity, including learners with different abilities, diverse cultural backgrounds, and varying levels of digital literacy, toward reducing the "Metaverse Divide."
4) Social interaction and collaboration research exploring social interactions, social presence, and community-building in the metaverse for fostering collaboration, peer-learning, and socioemotional development, including cross-cultural studies and global education, exploring the impact on learning outcomes.
5) Explore strategies for training educators to effectively leverage the metaverse as a learning tool, including developing pedagogical competencies and digital literacy skills for instructors.
6) Conduct longitudinal studies to assess the long-term effects of metaverse-based learning on knowledge retention and skill development, contributing to the evidence base for educational policymakers and practitioners.

The papers in this special issue highlight essential aspects, principles, and directions for future research on the *Edu-Metaverse*. These examples demonstrate how research-driven approaches can guide the development of educational metaverse experiences and how their effectiveness in facilitating learning can be evaluated.

Overall, we believe that this special issue serves as a practical reference for the development and design of education metaverse applications, contributing to standardization efforts in this emerging field, and aiming at documenting some of the critical challenges and opportunities generated by the nexus between education and the metaverse.

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Appendix
Related Articles

[A1] X. Chen, D. Zou, H. Xie, and F. L. Wang, "Metaverse in education: Contributors, cooperations, and research themes," *IEEE Trans. Learn. Technol.*, early access, May 19, 2023, doi: 10.1109/TLT.2023.3277952.

[A2] C. Villalonga-Gómez, E. Ortega-Fernández, and E. Borau-Boira, "Fifteen years of metaverse in higher education: A systematic literature review," *IEEE Trans. Learn. Technol.*, early access, Aug. 7, 2023, doi: 10.1109/TLT.2023.3302382.

[A3] Z. P. T. Sin et al., "Towards an Edu-Metaverse of knowledge: Immersive exploration of university courses," *IEEE Trans. Learn. Technol.*, early access, Jun. 29, 2023, doi: 10.1109/TLT.2023.3290814.

[A4] T. Kim, J. Planey, and R. Lindgren, "Theory-driven design in metaverse virtual reality learning environments: Two exemplary cases," *IEEE Trans. Learn. Technol.*, early access, Dec. 2023, doi: 10.1109/TLT.2023.3307211.

[A5] Z. Han, Y. Tu, and C. Huang, "A framework for constructing a technology-enhanced education metaverse: Learner engagement with human–machine collaboration," *IEEE Trans. Learn. Technol.*, early access, Mar. 15, 2023, doi: 10.1109/TLT.2023.3257511.

[A6] X. Chen, Z. Zhong, and D. Wu, "Metaverse for education: Technical framework and design criteria," *IEEE Trans. Learn. Technol.*, early access, May 16, 2023, doi: 10.1109/TLT.2023.3276760.

[A7] K. Zhang, Z. Shao, Y. Lu, Y. Yu, W. Sun, and Z. Wang, "Introducing massive open metaverse course (MOMC) and its enabling technology," *IEEE Trans. Learn. Technol.*, early access, Jun. 27, 2023, doi: 10.1109/TLT.2023.3289880.

[A8] S.-M. Lee, "Second Language learning through an emergent narrative in a narrative-rich customizable metaverse platform," *IEEE Trans. Learn. Technol.*, early access, Apr. 17, 2023, doi: 10.1109/TLT.2023.3267563.

[A9] T. Xie, Y. Li, and Y. Tang, "Effects of using immersive virtual reality for science education on learning outcomes: A randomized controlled pilot study," *IEEE Trans. Learn. Technol.*, early access, Dec. 2023, doi: 10.1109/TLT.2023.3263587.

[A10] F. Tian, J. Zou, K. Li, and Y. Li, "Kung Fu Metaverse: A movement guidance training system," *IEEE Trans. Learn. Technol.*, early access, Sep. 22, 2023, doi: 10.1109/TLT.2023.3317945.

[A11] X. Zhai, X. Chu, M. Chen, J. Shen, and F. Lou, "Can Edu-Metaverse reshape virtual teaching community (VTC) to promote educational equity? An exploratory study," *IEEE Trans. Learn. Technol.*, early access, May 16, 2023 2023, doi: 10.1109/TLT.2023.3276876.

[A12] Y. Song, J. Cao, K. Wu, P. L. H. Yu, and J. C.-K. Lee, "Developing 'Learningverse'—A 3D metaverse platform to support teaching, social and cognitive presences," *IEEE Trans. Learn. Technol.*, early access, May 2023, doi: 10.1109/TLT.2023.3276574.

REFERENCES

[1] S. Mystakidis, "Metaverse," *Encyclopedia*, vol. 2, no. 1, pp. 486–497, Feb. 2022, doi: 10.3390/encyclopedia2010031.

[2] M. Ball, *The Metaverse: And How It Will Revolutionize Everything*. New York, NY, USA: W.W. Norton, 2022.

[3] L. Zhang, Q. Du, L. Lu, and S. Zhang, "Overview of the integration of communications, sensing, computing, and storage as enabling technologies for the metaverse over 6G networks," *Electronics*, vol. 12, no. 17, Aug. 2023, Art. no. 3651, doi: 10.3390/electronics12173651.

[4] N. Stephenson, *Snow Crash*. New York, NY, USA: Bantam Books, 1992.

[5] Z. Chen, "Exploring the application scenarios and issues facing metaverse technology in education," *Interactive Learn. Environ.*, doi: 10.1080/10494820.2022.2133148.

[6] M. Wang, H. Yu, Z. Bell, and X. Chu, "Constructing an Edu-Metaverse ecosystem: A new and innovative framework," *IEEE Trans. Learn. Technol.*, vol. 15, no. 6, pp. 685–696, Dec. 2022, doi: 10.1109/TLT.2022.3210828.

[7] D. Beck, L. Morgado, and P. O'Shea, "Educational practices and strategies with immersive learning environments: Mapping of reviews for using the metaverse," *IEEE Trans. Learn. Technol.*, early access, Feb. 10, 2023, doi: 10.1109/TLT.2023.3243946.

[8] J. G. Wu, D. Zhang, and S. M. Lee, "Into the brave new metaverse: Envisaging future language teaching and learning," *IEEE Trans. Learn. Technol.*, early access, Mar. 23 2023, doi: 10.1109/TLT.2023.3259470.

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