Education and Information Technologies (2025) 30:17133–17153
https://doi.org/10.1007/s10639-025-13486-9

Conceptualizing and enhancing metaverse literacy for education

Andy Nguyen[1,2] · **Luna Huynh**[1] · **Belle Dang**[1] · **Sami Pohjolainen**[2] · **Juho Mattila**[2] · **Iikka J. Paajala**[2] · **Ruut Tikkanen**[3] · **Essi Lehto**[3] · **Fedja Poikonen**[2] · **Pasi Karppinen**[4]

Received: 30 October 2024 / Accepted: 3 March 2025 / Published online: 8 March 2025

Abstract
The metaverse has gained considerable attention and enormous investments in recent years and is increasingly recognized as a critical domain for future interactions and communications. Despite its growing importance, there is a notable lack of research on metaverse literacy, especially in education and training. This study aims to conceptualize "metaverse literacy for education" by defining its core components and proposing a framework for its evaluation. Furthermore, we report a case study leveraging an experiential learning approach to explore how exposure to various digital platforms - Virtual Reality (VR) headsets, mobile phones, and personal computers (PC) - influences metaverse literacy and perceptions regarding its adoption. The case study engaged first-year bachelor-level students (N=30) enrolled in an undergraduate program. Our findings reveal that learning experience with the metaverse significantly shifts students' perceptions about the effort needed for adoption and enhances their metaverse literacy for education. By focusing on these dimensions, this study makes a contribution to the understanding of metaverse literacy for education, advocating for an experiential approach to learning and adaptation in digital environments.

Keywords Metaverse · Experiential learning · Metaverse literacy · Conceptualization

✉ Andy Nguyen
andy.nguyen@oulu.fi

[1] Learning & Educational Technology Research Unit (LET), University of Oulu, Oulu, Finland

[2] Oulu Advanced Research on Service and Information Systems (OASIS) Research Group, University of Oulu, Oulu, Finland

[3] INTERACT Research Group, University of Oulu, Oulu, Finland

[4] imec-SMIT, Vrije Universiteit Brussel, Brussels, Belgium

1 Introduction

The emergence of the metaverse has presented a transformative landscape for digital interaction and communication thus has generated significant interest in its potential applications across various sectors (Kim, 2021; Zhang et al., 2024). This multidimensional platform integrates extended realities (XR) including augmented reality (AR) and virtual reality (VR) with blockchain technologies to create a seamless, immersive experience that transcends traditional digital engagement. Although the metaverse concept is closely associated with AR and VR, it is not confined to these technologies alone. The metaverse can also be accessed through more common devices such as mobile phones and personal computers (PCs). Research suggests that the metaverse could provide unique opportunities not only in education but also across various sectors (Hwang & Chien, 2022; Lin et al., 2022; Zhang et al., 2023). However, the effectiveness of such Metaverse-based environments in educational and work settings hinges critically on the users' ability to proficiently navigate and manipulate these spaces (Hwang et al., 2023).

While numerous academic research and industry experts have acknowledged the significant potential of the metaverse in shaping future societal interactions (e.g., Kim, 2021; Mystakidis, 2022), there remains a notable deficiency in studies focused on metaverse literacy among higher education students, especially in Information Systems (IS) education. Metaverse literacy extends beyond traditional digital skills, encompassing a broader spectrum of competencies that enable effective navigation, interaction, and creation within these complex virtual environments (Hwang et al., 2023). In particular, metaverse literacy involves a constellation of skills, including spatial navigation, digital citizenship, content creation, and the ability to engage interactively within a three-dimensional virtual space. These competencies are crucial for students to effectively utilize the metaverse for learning, social interaction, and eventually professional applications.

This study aims to conceptualize metaverse literacy and present a case study illustrating how experiential learning can be employed to enhance metaverse literacy and perceptions. The case study utilizes experiential learning (Kolb, 2014) and the theory of situated cognition (Brown et al., 1989) to investigate how varied exposure to digital platforms affects metaverse literacy and perceptions regarding its adoption. Experiential learning is an educational approach where learners acquire knowledge and skills through direct engagement in meaningful activities (Kolb, 2014), while situated cognition emphasizes that this learning occurs within and is influenced by the context or environment in which it takes place, highlighting the interdependence of thought processes and the physical and social aspects of learning environments (Brown et al., 1989). Furthermore, this research evaluates whether strategically sequenced exposure to different types of digital platforms results in more robust literacy than random or unstructured exposure. Research supports this approach, indicating that the design and modality of virtual environments significantly influence cognitive and affective learning outcomes (Johnson-Glenberg et al., 2020).

2 Opportunities and challenges of metaverse in education

The metaverse refers to a collection of virtual environments where users, represented by avatars, interact with one another, typically within three-dimensional (3D) spaces. It represents a world where the virtual and physical realms converge, co-evolving to support social, economic, and cultural activities that create value (Kye et al., 2021; Zhang & Quoquab, 2023). The metaverse goes beyond merely combining the physical and virtual worlds; it serves as a seamless extension of the physical world into the virtual realm, creating a unified ecosystem that integrates both environments. In this regard, the metaverse is commonly categorized in four types: (1) augmented reality, (2) lifelogging, (3) mirror world, and (4) virtual reality (George-Reyes et al., 2023). Access to the metaverse is possible through various digital devices, including headsets, smartphones, and personal computers, among others. Software and hardware availability leads to an increased interest and readiness to incorporate the metaverse into teaching and learning (Fortman & Quintana, 2023), marking education one of the most impactful sectors of the metaverse (Dwivedi et al., 2022).

The metaverse has garnered increasing interest from educators and researchers due to its transformative potential in reshaping learning practices. While many studies still subsume the afore-mentioned four categories under the broader term of the metaverse (Kye et al., 2021; Ng, 2022), technological advancements in recent years have reconceptualized the essential characteristics of the metaverse. Remarkably, Hwang and Chien (2022) emphasize the distinction between the metaverse and AR/VR by highlighting its key features of being *shared*,*persistent*, and *decentralized*. They note that the metaverse integrates AR and VR alongside other technologies, including AI, to create a more comprehensive and dynamic environment. In contrast to AR/VR, which primarily presents virtual content and environments, the metaverse fosters immersive experiences, collaboration, and interaction that support the development of cognitive and social learning (Ng, 2022). Specifically, the metaverse provides sensory-rich, experiential learning environments that promote embodied learning, enhance spatial knowledge, and offer opportunities for situated learning (Fortman & Quintana, 2023).

In addition, its multi-user environment facilitates global collaboration, allowing students from different geographical locations to work together in real-time, promoting intercultural competence and expanding the boundaries of traditional education (Dwivedi et al., 2022). Additionally, personalized learning and adaptive learning within the metaverse makes education more engaging and tailored to individual learner needs (Onu et al., 2024). Given its potential, the metaverse has been employed in various fields of education such as healthcare and medicine training (Kye et al., 2021). Particularly, it enables learners to participate more dynamically regardless of constraints on time or space, such as doing hands-on experiments, conducting virtual visits in a 3D environment (Huh, 2022). It is especially crucial in experiential learning in situations that may be hazardous or harmful in the real world, such as simulating radiation leaks, war zones, or emergency responses for elementary school students (Dwivedi et al., 2022).

Despite the exciting prospects, significant challenges remain in integrating the metaverse into education. Human factors, particularly the readiness of teachers and learners, stand as key obstacles to its successful implementation. From the teachers' perspective, the current scarcity of educational content in the metaverse makes it difficult to find and utilize relevant materials (Onu et al., 2024). This scarcity of resources also means that educators must develop meaningful curricula that effectively incorporate metaverse technologies. This task requires them to adapt to new teaching methods and identify a new set of skills necessary for learners, which can be daunting without proper training or pedagogical support (Tlili et al., 2022). From the students' perspectives, prolonged use of VR technologies can cause physical discomfort, such as VR sickness, raising concerns about student health and well-being in immersive learning environments (Dopsaj et al., 2024).

Additionally, while the metaverse promises to enhance learning through its features of presence, immersion, and agency, studies have shown that it does not always guarantee positive learning outcomes. Instead, it may hinder the learning performance by inducing extraneous cognitive processing and distracting learners. A lack of digital literacy, particularly immersive literacy, has been identified as a significant barrier in utilizing immersive environments effectively (Skulmowski, 2023). Furthermore, research indicates that time management in the virtual world can also pose challenges for students, as many do not possess the necessary technological knowledge to navigate the metaverse efficiently (Tlili et al., 2022). Without adequately preparing learners with the necessary literacies, the integration of the metaverse into education may hinder rather than enhance learning outcomes. This highlights the need to conceptualize Metaverse Literacy, equipping both learners and educators with the skills to navigate, understand, and critically engage with immersive technologies.

3 Conceptualizing metaverse literacy

3.1 Defining metaverse literacy

The concept of "literacy" has expanded considerably beyond its original definition of basic reading and writing skills to encompass a broad spectrum of competencies, including financial, health, and scientific literacies. In the digital era, digital literacy has emerged as a critical skill, encompassing related areas such as media literacy and information literacy. These literacies focus on individuals' abilities to effectively apply, evaluate, and communicate information within technology-mediated environments. As emerging technologies like AI and the metaverse continue to shape various aspects of society including education, corresponding literacies are increasingly necessary. While recent research has made progress in conceptualizing and measuring AI literacy (e.g., Celik, 2023; Ng et al., 2024), the development of metaverse literacy remains limited, despite significant investment in and the promising potential of this technology.

A few attempts have been made to explore metaverse literacy within specific professional contexts. For instance, Subaveerapandiyan et al. (2024) investigated metaverse literacy among library professionals, offering valuable insights into the specialized competencies required to navigate and manage virtual information ecosystems. Similarly, Hong et al. (2024) surveyed metaverse literacy among teachers, highlighting the specific learning needs and professional development required to integrate immersive technologies into classroom practices. However, both studies are quite context specific—the former focusing exclusively on library settings and the latter tailored to the educational demands of teachers. As a result, they do not fully capture the broader range of skills and adaptive strategies that learners in diverse educational settings require to effectively engage with the metaverse.

From our point of view, technology-related literacy goes beyond basic technical skills for operating technology and should be contextualized according to specific environments. For example, Ng et al. (2024) conceptualized AI literacy for educational contexts, drawing on Bloom's taxonomy to frame the necessary competencies. In line with this, we argue that while metaverse literacy could be grounded in the affordances of the metaverse to help learners navigate and engage meaningfully with virtual learning environments, its conceptualization for education is equally important. This educational focus is essential for maximizing the benefits of the metaverse in both learning and teaching.

Accordingly, metaverse literacy for education can be understood from multiple angles. It can involve understanding the technical and navigational skills needed to engage with virtual environments, the cognitive abilities required to critically assess and interact within these spaces, and the social and ethical dimensions of participating in immersive, digital ecosystems. Additionally, it can encompass the pedagogical implications, where educators and learners leverage the unique affordances of the metaverse to enhance teaching and learning processes. Each of these perspectives contributes to a more comprehensive understanding of metaverse literacy in an educational context.

Nevertheless, metaverse literacy for education should broadly refer to both technological proficiency and cognitive adaptability in learning within immersive settings as they are associated with a learner's perception of the metaverse environment. Learners need to master the interfaces and controls of metaverse environments to effectively navigate, engage with, and critically analyze immersive experiences, normally provided by Virtual Reality (VR) and Augmented Reality (AR) technologies (Steed et al., 2023). It also involves understanding spatial awareness in virtual spaces, performing embodied learning through interactions with digital objects (Di Natale et al., 2020), having the feeling of presence and sensory engagement, and critically reflecting on the impact of these immersive experiences on cognition and behavior (Steed et al., 2023).

Furthermore, collaboration and socio-emotional skills are also essential to the metaverse, where user avatars collaborate and share experiences, thus creating shared values. Unlike in the physical world, this virtual collaboration transcends time and space, fostering a sense of common purpose within the metaverse society. However, communication in the metaverse is limited by sensor data, which can lead to misunderstandings or misinterpretations of intentions (Dwivedi et al., 2022). Therefore, developing collaborative and socio-emotional skills to converse, negotiate, and evaluate the situations are important to facilitate smooth and meaningful interactions in the metaverse.

In the context of education, we define metaverse literacy as the set of abilities and self-efficacies needed to effectively and enjoyably utilize the metaverse for learning.

This includes competencies across cognitive, behavioural, and ethical dimensions, enabling learners to navigate, engage with, and reflect on their experiences within immersive virtual environments.

3.2 Evaluating metaverse literacy for education

The dimensionality of metaverse literacy for education can be framed by drawing on prior research on digital literacy. Specifically, building on the conceptualization of other technological literacy for education, particularly AI literacy framework proposed by Ng et al. (2024) and grounded in Bloom's taxonomy (Bloom, 1956; Krathwohl et al., 1964), the learning domains for metaverse literacy can be categorised into four main domains: affective, behavioural, cognitive, and ethical. These domains align with learners' abilities to engage emotionally, perform actions, process knowledge, and address moral considerations within the metaverse learning environments.

Moreover, prior research on technology adoption highlights that users' perceptions and their initial expectations play a critical role in influencing technology usage (Davis, 1989; Di Natale et al., 2020). These factors shape not only the likelihood of adoption but also the manner and extent to which users engage with new technological tools. Therefore, in evaluating metaverse literacy for educational purposes, we propose that it is essential not only to assess individuals' ability to utilize the metaverse effectively within learning contexts but also to consider their perceptions of the metaverse and their prior expectations. These factors are integral to understanding their overall readiness and potential engagement with metaverse-based educational environments. By integrating these aspects, we conceptualize the Metaverse Literacy for Education framework, as illustrated in Fig. 1.

The affective learning domain in Bloom's taxonomy, as originally outlined by Krathwohl et al. (1964), involves the development of students' attitudes, values, and emotions in learning contexts, which influence their motivation and engagement in educational activities. In this context of metaverse literacy, the affective learning domain encompasses students' emotions related to learning within the metaverse. This domain is pivotal in shaping how students value and emotionally relate to content, significantly impacting their learning outcomes (Anderson et al., 2001). It is

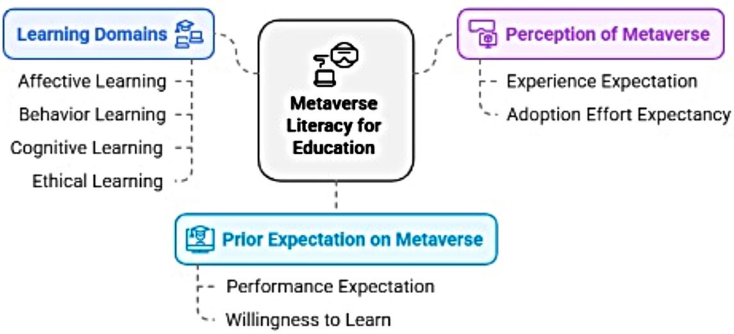

Fig. 1 Metaverse literacy for education framework

important to note that, unlike general attitudes toward technology (Davis, 1989; Di Natale et al., 2024) such as learners' perceptions of the metaverse, the affective learning domain within metaverse literacy for education specifically focuses on the emotional aspects of using the metaverse for learning. This includes how students feel about leveraging the metaverse as a tool to support their educational experiences. This includes their attitudes such as motivation, self-efficacy and confidence in participating and engaging in metaverse-based learning activities. For instance, it considers how comfortable students feel navigating the metaverse and how confident they are in utilizing its features to support their learning processes.

Behavioural learning focuses on the actions and external behaviours that demonstrate students' active engagement in learning within the metaverse. This encompasses operational performance, course completion rates, behavioural intentions, collaboration, and overall engagement in virtual spaces. Studies have examined how students' collaborative efforts and communication within virtual environments contribute to their learning outcomes, highlighting the importance of active participation in the metaverse.

Cognitive learning involves the development of thinking skills ranging from basic knowledge acquisition to higher-order critical thinking, as outlined in Bloom's taxonomy. In evaluating metaverse literacy, this dimension assesses students' growth in understanding virtual technologies, their ability to analyse and seek information within the metaverse, and the depth of their technological skills. Recent studies have utilized self-report questionnaires to gauge students' knowledge in areas such as navigation of virtual spaces, information processing, and problem-solving within digital environments (Fokides, 2023).

Ethical learning domain pertains to the moral principles and responsible practices associated with using metaverse technologies for education. Previous research emphasizes the need to contextualize ethical and privacy issues, particularly within educational settings (Ifenthaler & Schumacher, 2016; Nguyen et al., 2023). In this regard, fostering learners' ethical understanding specific to learning within the metaverse becomes essential, as it enables them to navigate digital environments responsibly and safely. This critical aspect extends beyond mere digital knowledge, encompassing issues like security, social responsibility, digital rights, privacy, and respectful interactions within virtual communities. Emphasizing ethical values enables students to use metaverse technologies responsibly, fostering a safe and respectful virtual environment while mitigating potential risks such as cyberbullying or misuse of digital information.

Furthermore, the perception of the metaverse and prior expectations significantly influence metaverse literacy in educational contexts, particularly regarding its use as a learning tool. When learners enter metaverse-based environments, their preconceived notions, such as whether positive or skeptical, affect their engagement and openness to using it for academic purposes. Positive perceptions and realistic expectations can enhance learners' confidence in exploring the metaverse's potential for interactive and immersive learning experiences, fostering a proactive approach to learning. Conversely, negative perceptions or inflated expectations may lead to disappointment or reluctance, reducing their willingness to fully engage with or explore the metaverse's capabilities. Consequently, learners' metaverse literacy is not merely about mastering technical aspects; it also involves developing a balanced understanding and adaptable mindset towards this new learning domain. Educators, therefore, need to address and guide these perceptions and expectations to support a smoother and more effective integration of the metaverse in educational practices.

By evaluating metaverse literacy through both these perception of the technology, prior expectation, and the four learning domains (affective, behavioural, cognitive, and ethical learning), educators can gain a comprehensive understanding of students' competencies in virtual environments. This holistic approach facilitates the development of targeted educational strategies that not only enhance students' technical skills but also promote responsible and meaningful engagement within the metaverse. Such evaluation is essential for preparing students to navigate the increasingly complex digital landscapes of the modern world effectively.

4 Case study for enhancing metaverse literacy through experiential learning

4.1 Participants and procedure

Participants in this study include first-year bachelor-level students ($N=30$) enrolled in the Information Systems (IS) program at [Remove for blind review]. Students were provided with different platforms of the metaverse, namely Metagallery, VRChat, and Spatial, accessed by PCs, VR headsets, or mobile phones. Screenshots of the learning environments are presented in Fig. 2.

Students were divided into three groups based on the sequence in which they engaged with different digital platforms: Group 1 ($N=9$) started with VR◊ Mobile ◊ PC; Group 2 ($N=9$) started with Mobile ◊ PC ◊ VR; Group 3 ($N=12$) started

Fig. 2 Metaverse environments used in this study

with PC ◊ VR ◊ Mobile. This design was informed by prior research indicating that the sequence of instructional activities can significantly influence learning outcomes (Roelle et al., 2022). However, our central hypothesis is that metaverse literacy—encompassing affective, behavioral, cognitive, and ethical dimensions—is context- and device-independent, meaning its development is robust regardless of the order of platform exposure. As illustrated in Fig. 3, by incorporating multiple sequences in our experimental design, we aimed to assess whether an experiential learning approach can promote transferable metaverse literacy skills across diverse digital environments and whether exposure to various platforms, irrespective of sequence, fosters a comprehensive set of these skills.

4.2 Measurements

This study employed pre-test and post-test data from two sets of 5-point Likert scale questionnaires concerning Metaverse Perception and Literacy for Learning Domains adapted from previous questionnaires on general technology perception and literacy on other technology (Di Natale et al., 2024; Ng et al., 2024). The Metaverse Perception includes Experience Expectation (7 items) and Effort Expectancy (4 items). The metaverse literacy for learning domains comprises of 4 sub constructs, namely Affective Learning (4 items), Behavioral Learning (3 items), Cognitive Learning (6 items), and Ethical Learning (5 items). In addition, we also surveyed their prior expectation with the metaverse as controlling factors, including their Performance Expectancy (4 items) and Willingness to learn with the metaverse (3 items). All questionnaires achieved a high Cronbach's alpha, indicating their high reliability (Table 1).

4.3 Data analysis

In this study, the effects of experiencing different digital platforms on students' metaverse perceptions and literacy were assessed using a variety of statistical techniques appropriate for the ordinal nature of the data and the study design. The data were

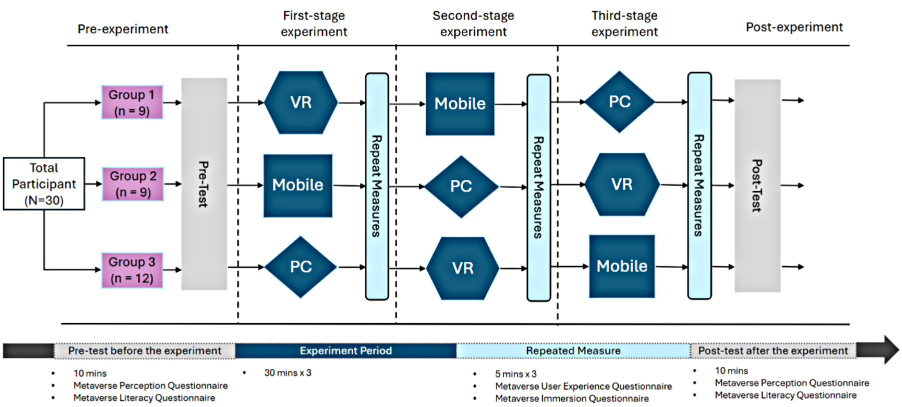

Fig. 3 The experiment design

Table 1 Reliability of the questionnaires used

Type	Scale	Cronbach's Alpha
Pre-questionnaire	Metaverse Prior Expectation (7 items)	0.8
	Metaverse Perception (11 items)	0.7
	Metaverse Literacy (Learning Domains) (18 items)	0.8
Post- questionnaire	Metaverse Perception (11 items)	0.8
	Metaverse Literacy (Learning Domains) (18 items)	0.9

analyzed using R programming (R Core Team, 2023), with the *lme4*, *lmerTest*, and *boot* packages.

A Linear Mixed-Effects Model (LMM) was used to assess changes between pre-test and post-test scores for the Metaverse Perception and Metaverse Literacy (Learning Domains) scales, while controlling for Willingness to use and Performance Expectancy. The model included Test Time (pre-test vs. post-test), Construct (with Experience Expectation as the reference), and their interaction to determine if changes differed across constructs. A random intercept was included for participants to account for repeated measures. The assumption of normal distribution was tested using the Shapiro-Wilk normality test, and homoscedasticity was assessed using the Breusch-Pagan test. The model was fit using restricted maximum likelihood (REML) estimation, and degrees of freedom were calculated using the Satterthwaite approximation. Due to the slight violation of the normality assumption and the small sample size, bootstrapping was applied to ensure accurate estimation of the fixed effects and confidence intervals. Bootstrapping was conducted with 1000 replications using the *bootMer* function from the *lme4* package, which resamples the data to provide robust confidence intervals and parameter estimates. This method effectively addresses issues related to non-normality and ensures reliable estimates despite the small sample size.

As participants were divided into three subgroups to follow three different learning sequences, we also explored the differences among the subgroups. Given the non-normality of the data and the small and unequal sample sizes across the three groups. Quade's Test - a non-parametric alternative to traditional ANCOVA that allows for the comparison of groups while adjusting for covariates, was employed to evaluate whether the sequence in which the groups used the metaverse platform had a significant effect on the learning outcomes, after controlling for the effects of Motivation and Performance Expectancy.

4.4 Results & findings

4.4.1 Impact of experiential learning across different digital platforms (VR, mobile, and PC) on students' metaverse perceptions and literacy

4.4.1.1 Metaverse perceptions Regarding their perception after learning with the metaverse platforms, a linear mixed-effects model was conducted to examine the changes in pre-test and post-test scores (Test Time) for their perception in terms of Effort Expectancy and Experience expectation (Construct), while controlling for Willingness to use and Performance Expectancy. The model included random intercepts for participants to account for repeated measures. The distribution of residuals was also tested, which showed a normal distribution. The results are presented in Table 2.

The analysis revealed a significant increase in scores from pre-test to post-test (b=0.37, SE=0.13, t(87)=2.86, *p*=.005), indicating that, on average, participants' perception toward learning with the Metaverse significantly increased across both constructs, after adjusting for Willingness to use and Performance Expectancy. However, the main effect for construct was not significant, showing that although Experience Expectation scores were estimated to be lower than Effort expectancy scores (b=−0.22, SE=0.13, t(87)=−1.72, *p*=.090), this difference is not remarkable.

Importantly, the interaction test revealed the changes in pre-test and post-test scores differed by construct (b=−0.49, SE=0.18, *t*(87)=−2.70, *p*=. 008). Specifically, the improvement in post-test scores was significantly higher for Effort expectancy compared to Experience Expectation, suggesting that participants experienced greater gains in Effort Expectancy after the intervention, even after controlling for Willingness to use and Performance Expectancy.

Furthermore, Willingness to use was a significant positive predictor of overall scores (b=0.26, SE=0.10, *t*(27)=2.61, *p*=.014), with higher Willingness to use being associated with higher scores, regardless of the pre-post test scores or construct of measurements. Performance Expectancy, however, did not significantly influence the scores (b=0.11, SE=0.10, *t*(27)=1.12, *p*=.272). The conditional R_c^2 = 0.383 showed that the full model, including both fixed and random effects, explained 38.3% of the variance, also reflecting a moderate amount of variance explained, accounting for individual differences among participants.

4.4.1.2 Metaverse literacy (learning domains) Another Linear Mixed-Effects Model (LMM) was conducted to analyse the differences between pre-test and post-test scores across the four constructs of the Metaverse Literacy scale (Cognitive Learning, Affective Learning, Behavioural Learning, and Ethical Learning), while controlling for Willingness to use and Performance Expectancy (Table 3). The model included Test

Table 2 Linear Mixed-Effects model for metaverse perception scale

Effects	Estimate	SE	df	t	*p*
Intercept	2.04	0.39	29.3	5.22	**<0.001*** **
Test Time (Pre-Post)	0.37	0.13	87	2.86	**0.005** **
Construct	-0.22	0.13	87	-1.72	0.09
Willingness to use	0.26	0.1	27	2.61	**0.014***
Performance Expectancy	0.11	0.1	27	1.12	0.272
Time × Construct Interaction	-0.49	0.18	87	-2.7	**0.008***

Note: R_m^2=0.286, R_c^2=0.383. Construct: Experience Expectation

Table 3 Linear mixed model results for metaverse literacy (Learning Domains) scale with bootstrap estimates

Effects	Estimate	BootBias	BootSE	t	*p*	95% Boot CI
Intercept	1.52	0.0021	0.37	4.09	<0.001***	(0.76, 2.24)
Test Time (Pre-test)	-0.82	-0.0043	0.13	-6.17	<0.001***	(-1.03, -0.55)
Behavioral Learning	-0.04	0.0007	0.13	-0.29	0.769	(-0.30, 0.21)
Ethical Learning	1.52	0.0009	0.13	11.48	<0.001***	(1.27, 1.77)
Affective Learning	1.2	-0.0049	0.13	9.09	<0.001***	(0.95, 1.44)
Willingness to use	0.24	0.0004	0.09	2.54	0.017*	(0.08, 0.39)
Performance	0.32	-0.001	0.1	3.26	0.003**	(0.12, 0.51)
TestTime × Behavioral_L.	0.85	0.0005	0.19	4.54	<0.001***	(0.48, 1.22)
TestTime × Ethical_L.	0.69	0.0063	0.19	3.68	<0.001***	(0.32, 1.06)
TestTime × Affective L.	0.55	0.0114	0.19	2.91	0.004**	(0.18, 0.93)

Note: R_m^2=0.518, R_c^2=0.602

Time (pre-test vs. post-test), Construct, and their interaction to determine whether the changes differed across the constructs. Cognitive Learning served as the reference construct, as it is considered the foundation for higher-order thinking, learners' affects, and behavioural changes in learning (Merrill, 2002). A random intercept for participants was included to account for repeated measures, allowing the model to adjust for individual differences in baseline scores. Given the small sample size and slight non-normality (as indicated by the Shapiro-Wilk test, W = 0.99, *p* = .046), bootstrapping with 1000 replications was employed to provide more reliable parameter estimates and confidence intervals. The intercept of the model, representing the pre-test baseline for Cognitive Learning, was estimated at b = 1.52 (bootSE = 0.37, *t*(203) = 4.09, *p* < .001), indicating that participants started with an average score of 1.52 in the Cognitive Learning construct prior to the intervention. The model included a random intercept for participants, reflecting individual differences in baseline scores. The variance for the random intercept was 0.056 (SD = 0.236). The model explained a significant portion of the variance in Metaverse Literacy (Learning Domains) scores, with the fixed effects accounting for 51.8% of the variance (R_m^2 = 0.518) and the full model, including both fixed and random effects, explaining 60.2% of the variance (R_c^2 = 0.602). Both values indicate a large effect size, suggesting that the predictors in the model explain a substantial amount of variance in Metaverse Literacy scores.

The analysis revealed a significant improvement in Metaverse Literacy (Learning Domains) scores from pre-test to post-test. Post-test scores in Cognitive Learning, the reference construct, were significantly higher compared to pre-test scores (b = 1.52, bootSE = 0.37, *p* < .001), indicating substantial gains following the intervention. Compared to Cognitive learning, Ethical Learning showing the largest improvement (b = 1.52, bootSE = 0.13, *t*(203) = 11.48, *p* < .001), indicating a larger gain in post-test scores. Similarly, Affective Learning also showed a significantly greater improvement compared to Cognitive Learning (b = 1.2, bootSE = 0.13, *t*(203) = 9.09, *p* < .001). Behavioral Learning also improved from pre-test to post-test, with a level of improvement similar to that of Cognitive Learning (b = -0.04, bootSE = 0.13, *t*(203) = -0.29, *p* = .769), indicating that the magnitude of the change was comparable to the reference construct.

Table 4 Quade's test results (on Residuals) for metaverse perception and metaverse Literacy(Learning Domains) across three learning sequences

Constructs	χ^2	df	*N*	*p*-value
Experience Expectation	3.12	2	30	0.211
Effort Expectancy	0.61	2	30	0.738
Affective Learning	0.05	2	30	0.977
Behavioural Learning	4.22	2	30	0.121
Cognitive Learning	4.29	2	30	0.117
Ethical Learning	0.22	2	30	0.897

Both Willingness to use and Performance Expectancy had a significant impact on the overall change in Metaverse Literacy (Learning Domains) scores from pre-test to post-test. Higher Willingness to use was associated with significantly greater improvements across the subscales (b=0.24, bootSE=0.09, $t(27)=2.54$, $p=.017$). Similarly, higher Performance also contributed to greater overall improvements across the constructs (b=0.32, bootSE=0.10, $t(27)=3.26$, $p=.003$).

The interaction between Test Type and Construct was significant, suggesting that the extent of improvement varied by construct. For example, the improvement in Affective Learning was significantly smaller than in Cognitive Learning (b = -0.55, bootSE=0.19, $t(203)$ = -2.91, $p=.004$), indicating that the difference in the amount of improvement between these two constructs was statistically significant. A similar pattern was observed in Behavioral Learning, which also showed significantly less improvement than Cognitive Learning (b = -0.85, bootSE=0.19, $t(203)$ = -4.54, $p<.001$). While Ethical Learning improved slightly less than Cognitive Learning (b = -0.69, bootSE=0.19, $t(203)$ = -3.68, $p<.001$), it still demonstrated a greater improvement than Affective Learning and Behavioral Learning. Overall, the results indicated that participants who reported greater Willingness to use and Performance Expectancy tended to have larger improvements in their Metaverse Literacy (Learning Domains) scores across all constructs.

4.4.2 Effects of exposure sequence to different digital platforms on the enhancement of students' metaverse perceptions and literacy

A series of Quade's Tests were conducted to examine whether there were significant differences in learners' Metaverse Perception and Literacy across three different learning sequences (VR, PC, and Mobile), while controlling for Willingness to use and Performance as covariates. The tests adjusted for the effects of these covariates before comparing the differences in learning outcomes across three learning sequences. The results are reported in Table 4.

As for Metaverse Perception, Quade's Test indicated no statistically significant differences between the three learning sequences in Experience Expectation, Qu, $\chi^2(2, N=30)=3.12$, $p=.211$. Similarly, for Effort Expectancy, the result was not statistically significant, $\chi^2(2, N=30)=0.61$, $p=.738$. This indicates that the sequence in which learners used the VR, PC, and Mobile platforms did not result in significant differences in their perception of the metaverse.

No significant differences were found in the four constructs of Metaverse Literacy (Learning Domains) scale. For Affective Learning, the Quade's Test results indicated that there were no statistically significant differences in residuals between the three groups, $\chi^2(2, N=30)=0.05$, $p=.977$. Similarly, for Behavioral Learning, although the test statistic suggested some variability between the groups, the p-value was above the conventional threshold for statistical significance, with $\chi^2(2, N=30)=4.22$, $p=.121$. In the case of Cognitive Learning, the Quade's Test also failed to find significant differences between the groups, $\chi^2(2, N=30)=4.29$, $p=.117$. Finally, for Ethical Learning, Quade's Test revealed no significant differences between the groups, $\chi^2(2, N=30)=0.22$, $p=.897$. Overall, the results of Quade's Tests across all Metaverse Literacy (Learning Domains) sub-scales indicated that participants, regardless of the learning sequence they experienced, did not show significant changes in their pre-post test scores for Affective Learning, Behavioral Learning, Cognitive Learning, or Ethical Leadership, after adjusting for Willingness to use and Performance.

5 Discussion

This conceptual paper sets out to define and frame metaverse literacy within an educational context. According to Statista, the metaverse market is anticipated to grow at a compound annual growth rate (CAGR) of 37.73% between 2024 and 2030, with a projected market volume reaching $507.8 billion by 2030 (*Metaverse - Worldwide*, 2024). Despite this rapid expansion and the metaverse's potential to impact multiple life domains (Ng, 2022), including education (Di Natale et al., 2024; Fokides, 2023), a clear definition of metaverse literacy, particularly for educational applications, remains largely unexplored. By contextualizing metaverse literacy and drawing on frameworks from other forms of technology literacy in education, this study represents one of the first efforts to conceptualize metaverse literacy for education.

Our work contributes to digital literacy literature by specifically advancing the discourse on metaverse literacy in education. We propose the framework of metaverse literacy for education through four learning domains based on Bloom's taxonomy (Bloom, 1956; Krathwohl et al., 1964; Ng et al., 2024): cognitive, affective, behavioral, and ethical. Additionally, the proposed framework incorporates learners' perceptions of the metaverse and their prior expectations, offering a comprehensive approach to metaverse literacy. The proposed framework not only offers a tool for assessing students' readiness to effectively engage with metaverse technologies in learning but also opens discussions on preparing students, especially those in higher education, for a future where these rapidly evolving technologies will likely become integral to professional and everyday life. Through this conceptualization, we aim to support educators and policymakers in integrating metaverse literacy as a critical component of digital education, fostering competencies that align with both current technological trends and anticipated future demands.

Adopting the proposed Metaverse Literacy for Education framework, this paper also presents a case study that offers insights into how experiential learning across different digital platforms can enhance metaverse literacy related to learning domains and students' adoption perceptions. Since metaverse literacy can sometimes be mistaken for extended reality literacy (e.g., Chang et al., 2023), this case study broadens the scope by enhancing metaverse literacy through multiple devices - not only using VR headsets but also incorporating mobile phones and PCs. Additionally, the case study examines how the sequence of platform exposure might influence these outcomes. The study explored metaverse literacy across cognitive, affective, behavioural, and ethical learning domains. Results from the Linear Mixed-Effects Model, enhanced with bootstrapping for robustness, indicated significant improvements across all literacy domains from pre-test to post-test, with Ethical Learning demonstrating the most substantial gains, followed by Affective and Behavioural Learning. This pattern suggests that students not only improved in their cognitive understanding but also enhanced their values, emotional responses, and ethical considerations associated with metaverse usage.

6 Theoretical and practical implications

6.1 Theoretical implications

Aligned with research on other forms of digital literacy, such as AI literacy for education (Celik, 2023; Ng et al., 2024), our study highlights the critical role of ethical learning in digital literacy for emerging technologies like the metaverse in educational settings. Remarkably, the Ethical Learning domain's prominent increase reflects growing awareness and sensitivity toward privacy, ethics, and responsibility, which are critical for meaningful engagement within digital platforms like the metaverse. Cognitive Learning improvements, serving as a foundation, further supported the development of other learning domains, emphasizing the role of comprehensive platform engagement in metaverse literacy.

The analysis using a linear mixed-effects model also demonstrated a significant overall improvement in students' perception of metaverse adoption following the intervention, specifically in terms of Effort Expectancy. Participants reported higher post-test scores compared to pre-test scores, indicating a positive shift in their perception of the metaverse's usefulness and usability. Moreover, the improvement in Experience Expectation following the Metaverse exposure indicates that participants perceived their experience with the Metaverse to be better than initially expected. This positive shift suggests that the Metaverse provided a more enriching and engaging experience than traditional methods, thereby enhancing learners' willingness to continue using it in the future (Di Natale et al., 2024). Furthermore, the results show that the increase in Effort Expectancy was significantly higher than in Experience Expectation, suggesting that students' willingness to engage with the metaverse improved more substantially than their expectations for a seamless experience. This finding implies that while exposure to metaverse platforms enhances students' readiness to adopt, it may not entirely align with their experiential expectations.

In terms of platform exposure sequence, this study found no statistically significant differences in students' metaverse perception or literacy across the VR, PC, and mobile platform orders. While the study highlights the potential of using an experiential learning approach (Kolb, 2014) to enhance metaverse literacy across various learning domains, it also indicates that the order in which learners are exposed to different platforms may not significantly impact the outcomes. The lack of significant differences across metaverse literacy constructs related to learning domains - such as

Affective, Behavioral, Cognitive, and Ethical Learning - further supports the conclusion that metaverse literacy development may rely more on cross-platform experience rather than specific sequences. Such findings highlight that exposure to diverse digital environments promotes metaverse literacy broadly without being constrained by a particular order, highlighting the flexibility and transferability of metaverse skills across platforms.

6.2 Practical implications

This study has important implications for learners, teachers, teacher educators, institutional managers, and policymakers in fostering metaverse literacy within education. For learners, the findings emphasize the importance of well-rounded literacy that includes ethical, cognitive, affective, and behavioral dimensions, enabling responsible and informed engagement in metaverse environments. The observed growth in Ethical Learning suggests a heightened sensitivity to privacy and ethics, essential for navigating digital spaces thoughtfully. For teachers, the results advocate for a multi-platform approach, demonstrating that diverse digital experiences can effectively enhance metaverse literacy across learning domains without being limited by platform order. Addressing students' initial perceptions and expectations is also crucial, as an open and positive approach to new technologies can significantly improve their readiness to adopt and benefit from the metaverse.

Moreover, this study offers educators a detailed framework for identifying key learning outcomes to target when integrating metaverse technologies into instruction. By delineating the specific dimensions of metaverse literacy, the research informs teachers about the contexts and subjects where metaverse-based approaches are most effective. This clarity streamlines instructional design, enabling teachers to allocate resources more efficiently and align lesson objectives with the technological affordances of the metaverse. Consequently, educators can adopt a more focused and effective pedagogical strategy that saves time and enhances overall teaching quality. For teacher educators, our findings indicate that professional development programs for teachers should include comprehensive training on metaverse technologies—not only to build technical skills but also to cultivate ethical, cognitive, and socio-emotional competencies. Such training will empower educators to design innovative, cross-platform learning experiences that promote critical thinking and responsible digital citizenship.

For institutional managers, our findings suggest that when adopting the Metaverse for educational purposes, schools and institutions should consider learners' anticipated perceptions of technology. This is in line with prior research indicating that Performance Expectancy plays a significant role as a direct determinant of user acceptance and the likelihood of adopting and continuing to use technology (Di Natale et al., 2024). Interventions aimed at improving students' beliefs about Metaverse's potential to enhance learning outcomes and their willingness to use it can help maximize the benefits of the technology. Our findings also revealed that learners who were more willing to use Metaverse tended to have better overall experiences and more developed literacy. Performance Expectancy, however, specifically impacted the literacy dimensions only, as this construct is directly related to learning and perceived performance benefits (Ledesma-Chaves et al., 2024).

For policymakers, the study highlights the importance of strategic investments in digital infrastructure and teacher training programs that support the integration of metaverse literacy into educational curricula. Policy initiatives should promote flexibility in instructional design and ensure that schools have access to diverse digital platforms, thereby preparing students for an increasingly digital future. Altogether, these insights highlight the value of integrating metaverse literacy into educational curricula, equipping students for responsible and adaptive participation in digital ecosystems for learning and teaching.

7 Final remarks, limitations, and directions for future research

In conclusion, this study defines and conceptualizes metaverse literacy specifically for education, providing a framework that encompasses key learning dimensions (cognitive, affective, behavioral, and ethical) alongside perceptions and prior expectations of the metaverse to support comprehensive literacy for learning within the metaverse. This framework addresses the rapid expansion of the metaverse market and the growing need for educational readiness in integrating this technology for learning and teaching. This framework is illustrated through a case study aimed at evaluating and enhancing metaverse literacy among higher education students. Furthermore, through an experiential learning approach and cross-platform engagement, the case study demonstrates that metaverse literacy can be significantly enhanced across learning domains.

This study has several limitations. The first limitation concerns the conceptualization of metaverse literacy for education. Although our framework is grounded in Bloom's taxonomy and informed by prior research on digital literacies, such as AI literacy for education, metaverse literacy could be conceptualized and assessed from alternative perspectives. Another limitation relates to the small sample size in the case study, which may affect the generalizability of the findings. Nonetheless, the case study effectively serves its purpose by illustrating the proposed framework for metaverse literacy in education and demonstrating an approach to enhance metaverse literacy. Future research could validate and refine our proposed framework across diverse contexts to strengthen its applicability.

Additionally, further research should investigate the long-term impacts of metaverse literacy education on student learning within this environment. Studies might also explore how metaverse literacy training affects professional readiness, particularly in fields where the metaverse and related technologies are expected to become integral. These research directions will support a more comprehensive understanding of metaverse literacy as an essential part of digital education, enhancing academic and professional preparedness in increasingly digitalized settings.

Appendix 1

Appendix A Questionnaires

Constructs	Items
Metaverse prior experience	
Performance Expectancy	Metaverse is useful in my daily life.
	Using metaverse increases my chances of achieving things that are important to me.
	Using metaverse helps me accomplish things more quickly.
	Using metaverse increases my productivity.
Willing to learn with the metaverse	Using metaverse will be fun.
	Using metaverse will be enjoyable.
	Using metaverse is going to be very entertaining.
Metaverse perception	
Experience Expectation	I anticipate being highly absorbed in the experience.
	I expect to lose track of time to a great extent.
	I believe I will feel like I am part of the virtual world.
	I think the experience will feel very real or authentic to me.
	I anticipate being emotionally involved in the experience.
	I expect to forget about my surroundings during the experience.
	I predict finding the task or activity to be very challenging.
Metaverse Literacy (Learning Domains)	
Effort Expectancy	Learning how to use metaverse is easy for me.
	My interaction with metaverse is clear and understandable
	I find metaverse easy to use.
	It is easy for me to become skilful at using metaverse.
Affective learning	I am confident I will perform well on metaverse related tasks.
	I am confident I will do well on metaverse related projects.
	I believe I can master metaverse knowledge and skills.
	I believe I can earn good grades in metaverse related assessments.
Behavioural Learning	I will continue to use metaverse in the future.
	I will keep myself updated with the latest metaverse technologies.
	I plan to spend time exploring new features of metaverse applications in the future.
Cognitive Learning	I know what metaverse is and recall the definitions of metaverse.
	I know how to use metaverse applications (e.g., Spatial).
	I can compare the differences between metaverse and relevant concepts (e.g., Virtual Reality, Mixed Reality).
	I can apply metaverse applications to solve problems.
	I can create Metaverse-driven solutions (e.g., with Spatial) to solve problems.
	I can evaluate metaverse applications and concepts for different situations.
Ethical Learning (5 items)	I understand how misuse of metaverse could result in substantial risk to humans.
	I think that users are responsible for considering metaverse design and decision processes.
	I think that metaverse systems should benefit everyone, regardless of physical abilities and gender.
	I think that users should be made aware of the purpose of the system, how it works and what limitations may be expected.
	I think that metaverse systems should meet ethical and legal standards.

Acknowledgements This research has been funded by [Removed for blind review].

Funding Open Access funding provided by University of Oulu (including Oulu University Hospital). This research has funded by the Research Council of Finland grants 350249 as well as Oulu University profiling project Profi7 Hybrid Intelligence 352788.

Data availability The data is not publicly available due to privacy consent restrictions but can be accessed upon request and completion of data transfer agreements.

Declarations

Ethical approval The study adheres to the ethical guidelines from the Ethics Committee of Human Sciences at [Removed for blind review]. Informed consent was obtained from all participants prior to their involvement in the study.

Conflict of interest The authors have NO conflict of interest to disclose.

References

Anderson, L. W., Krathwohl, D. R., & Bloom, B. S. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. Allyn & Bacon.

Bloom, B. S. (1956). Taxonomy of educational objectives. 1: Cognitive domain. *New York: McKay*, 20–24.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *1989*, *18*(1), 32–42.

Celik, I. (2023). Towards Intelligent-TPACK: An empirical study on teachers' professional knowledge to ethically integrate artificial intelligence (AI)-based tools into education. *Computers in Human Behavior*, *138*, 107468. https://doi.org/10.1016/j.chb.2022.107468

Chang, C. Y., Kuo, H. C., & Du, Z. (2023). The role of digital literacy in augmented, virtual, and mixed reality in popular science education: A review study and an educational framework development. *Virtual Reality*, *27*(3), 2461–2479. https://doi.org/10.1007/s10055-023-00817-9

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 319–340.

Di Natale, A. F., Repetto, C., Riva, G., & Villani, D. (2020). Immersive virtual reality in K-12 and higher education: A 10-year systematic review of empirical research. *British Journal of Educational Technology*, *51*(6), 2006–2033. https://doi.org/10.1111/bjet.13030

Di Natale, A. F., Bartolotta, S., Gaggioli, A., Riva, G., & Villani, D. (2024). Exploring students' acceptance and continuance intention in using immersive virtual reality and metaverse integrated learning environments: The case of an Italian university course. *Education and Information Technologies*. https://doi.org/10.1007/s10639-023-12436-7

Dopsaj, M., Tan, W., Perovic, V., Stajic, Z., Milosavljevic, N., Paessler, S., & Makishima, T. (2024). Novel neurodigital interface reduces motion sickness in virtual reality. *Neuroscience Letters*, *825*, 137692. https://doi.org/10.1016/j.neulet.2024.137692

Dwivedi, Y. K., Hughes, L., Baabdullah, A. M., Ribeiro-Navarrete, S., Giannakis, M., Al-Debei, M. M., Dennehy, D., Metri, B., Buhalis, D., Cheung, C. M. K., Conboy, K., Doyle, R., Dubey, R., Dutot, V., Felix, R., Goyal, D. P., Gustafsson, A., Hinsch, C., Jebabli, I., & Wamba, S. F. (2022). Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *International Journal of Information Management*, *66*, 102542. https://doi.org/10.1016/j.ijinfomgt.2022.102542

Fokides, E. (2023). Development and testing of a scale for examining factors affecting the learning experience in the metaverse. *Computers & Education: X Reality*, *2*, 100025. https://doi.org/10.1016/j.cexr.2023.100025

Fortman, J., & Quintana, R. (2023). Fostering collaborative and embodied learning with extended reality: Special issue introduction. *International Journal of Computer-Supported Collaborative Learning*, *18*(2), 145–152. https://doi.org/10.1007/s11412-023-09404-1

George-Reyes, C. E., Peláez Sánchez, I. C., Glasserman-Morales, L. D., & López-Caudana, E. O. (2023). The metaverse and complex thinking: Opportunities, experiences, and future lines of research. *Frontiers in Education*, *8*, 1166999. https://doi.org/10.3389/feduc.2023.1166999

Huh, S. (2022). Application of computer-based testing in the Korean medical licensing examination, the emergence of the metaverse in medical education, journal metrics and statistics, and appreciation to reviewers and volunteers. *Journal of Educational Evaluation for Health Professions*, *19*, 2. https://doi.org/10.3352/jeehp.2022.19.2

Hwang, G. J., & Chien, S. Y. (2022). Definition, roles, and potential research issues of the metaverse in education: An artificial intelligence perspective. *Computers and Education: Artificial Intelligence*, *3*, 100082. https://doi.org/10.1016/j.caeai.2022.100082

Hwang, G. J., Tu, Y. F., & Chu, H. C. (2023). Conceptions of the metaverse in higher education: A draw-a-picture analysis and surveys to investigate the perceptions of students with different motivation levels. *Computers & Education*, *203*, 104868. https://doi.org/10.1016/j.compedu.2023.104868

Ifenthaler, D., & Schumacher, C. (2016). Student perceptions of privacy principles for learning analytics. *Educational Technology Research and Development*, *64*(5), 923–938. https://doi.org/10.1007/s11423-016-9477-y

Johnson-Glenberg, M. C., Ly, V., Su, M., Zavala, R. N., Bartolomeo, H., & Kalina, E. (2020). Embodied agentic STEM education: Effects of 3D VR compared to 2D PC. In *2020 6th international conference of the immersive learning research network (ilrn)* (pp. 24–30). IEEE. https://doi.org/10.23919/iLRN47897.2020.9155155

Kim, J. (2021). Advertising in the metaverse: Research agenda. *Journal of Interactive Advertising*, *21*(3), 141–144. https://doi.org/10.1080/15252019.2021.2001273

Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development*. FT press. https://books.google.com/books?hl=en&lr=&id=jpbeBQAAQBAJ&oi=fnd&pg=PR7&dq=experiential+learning&ots=Vp3RpS_VN9&sig=wi1OzKjTphnszRiNpo-NdzdDMb0

Krathwohl, D. R., Bloom, B. S., & Masia, B. B. (1964). *Taxonomy of educational objectives: The classification of educational goals: Handbook II: Affective domain*. David McKay Company. https://eduq.info/xmlui/handle/11515/11943

Kye, B., Han, N., Kim, E., Park, Y., & Jo, S. (2021). Educational applications of metaverse: Possibilities and limitations. *Journal of Educational Evaluation for Health Professions*, *18*, 32. https://doi.org/10.3352/jeehp.2021.18.32

Ledesma-Chaves, P., Gil-Cordero, E., Navarro-García, A., & Maldonado-López, B. (2024). Satisfaction and performance expectations for the adoption of the metaverse in tourism SMEs. *Journal of Innovation & Knowledge*, *9*(3), 100535. https://doi.org/10.1016/j.jik.2024.100535

Lin, H., Wan, S., Gan, W., Chen, J., & Chao, H. C. (2022). Metaverse in education: Vision, opportunities, and challenges. *2022 IEEE International Conference on Big Data (Big Data)*, 2857–2866. https://ieeexplore.ieee.org/abstract/document/10021004/

Merrill, M. D. (2002). First principles of instruction. *Educational Technology Research and Development*, *50*(3), 43–59. https://doi.org/10.1007/BF02505024

Metaverse—Worldwide. (2024). Statista. https://www.statista.com/outlook/amo/metaverse/worldwide

Mystakidis, S. (2022). *Metaverse Encyclopedia*, 2(1), 486–497.

Ng, D. T. K. (2022). What is the metaverse? Definitions, technologies and the community of inquiry. *Australasian Journal of Educational Technology*, *38*(4), 190–205. https://doi.org/10.14742/ajet.7945

Ng, D. T. K., Wu, W., Leung, J. K. L., Chiu, T. K. F., & Chu, S. K. W. (2024). Design and validation of the AI literacy questionnaire: The affective, behavioural, cognitive and ethical approach. *British Journal of Educational Technology*, *55*(3), 1082–1104. https://doi.org/10.1111/bjet.13411

Nguyen, A., Ngo, H. N., Hong, Y., Dang, B., & Nguyen, B. P. T. (2023). Ethical principles for artificial intelligence in education. *Education and Information Technologies*, *28*(4), 4221–4241. https://doi.org/10.1007/s10639-022-11316-w

Onu, P., Pradhan, A., & Mbohwa, C. (2024). Potential to use metaverse for future teaching and learning. *Education and Information Technologies*, *29*(7), 8893–8924. https://doi.org/10.1007/s10639-023-12167-9

R Core Team. (2023). *R: A Language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Roelle, J., Froese, L., Krebs, R., Obergassel, N., & Waldeyer, J. (2022). Sequence matters! Retrieval practice before generative learning is more effective than the reverse order. *Learning and Instruction*, *80*, 101634. https://doi.org/10.1016/j.learninstruc.2022.101634

Skulmowski, A. (2023). Ethical issues of educational virtual reality. *Computers & Education: X Reality*, *2*, 100023. https://doi.org/10.1016/j.cexr.2023.100023

Steed, A., Archer, D., Izzouzi, L., Numan, N., Shapiro, K., Swapp, D., Lammiman, D., & Lindeman, R. W. (2023). Immersive competence and immersive literacy: Exploring how users learn about immersive experiences. *Frontiers in Virtual Reality*, *4*, 1129242. https://doi.org/10.3389/frvir.2023.1129242

Subaveerapandiyan, A., Baiju, A., Ahmad, N., Verma, M. K., & Sinha, P. (2024). Exploring metaverse literacy: Immersive technologies in library environments. *Journal of Web Librarianship*, *18*(2), 39–63. https://doi.org/10.1080/19322909.2024.2382688

Tlili, A., Huang, R., Shehata, B., Liu, D., Zhao, J., Metwally, A. H. S., Wang, H., Denden, M., Bozkurt, A., Lee, L. H., Beyoglu, D., Altinay, F., Sharma, R. C., Altinay, Z., Li, Z., Liu, J., Ahmad, F., Hu, Y., Salha, S., & Burgos, D. (2022). Is metaverse in education a blessing or a curse: A combined content and bibliometric analysis. *Smart Learning Environments*, *9*(1), 24. https://doi.org/10.1186/s40561-022-00205-x

Zhang, J., & Quoquab, F. (2023). Metaverse in the urban destinations in China: Some insights for the tourism players. *International Journal of Tourism Cities*, *9*(4), 1016–1024. https://doi.org/10.1108/IJTC-04-2023-0062

Zhang, J., Quoquab, F., & Mohammad, J. (2023). Metaverse tourism and Gen-Z and Gen-Y's motivation: Will you, or won't you travel virtually? *Tourism Review*, *79*(2), 304–320. https://doi.org/10.1108/TR-06-2023-0393