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The Upsurge of the Metaverse in Educational Settings: A Meta-analysis Study

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Abstract

The metaverse has the potential to revolutionise education in several ways. It can provide students with immersive learning experiences, allowing them to explore and interact with virtual worlds and objects that are difficult or impossible to replicate in the real world. Yet, studies investigating the impact of the metaverse on students' skills and performance are limited due to its novelty. The key objective of the current research is to unveil the overall effect size of integrating metaverse technologies into educational contexts and the significance of several factors that could influence the effectiveness of such technology on the learning ecosystem. The research as adopted the quantitative research methodology to address the research questions, which focused on following the principles of meta-analysis with calculating the effect size of relevant studies, by mainly using PRISMA. It an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses. Accordingly, twenty-four experimental studies conducted between 2020–2023 were statistically analysed. The results have explicitly that employing the metaverse generally has a large effect size (d=0.94) on learning, indicating that integrating the metaverse in educational settings can significantly enhance students' performance. Other variables, such as educational level, skills targeted, subject taught and technology used, were also investigated. A discussion of these findings and their implications are presented.
Keywords: Metaverse, Meta-analysis, Effect-size, Effectiveness, PRISMA

Introduction

The metaverse is a trend with potential emerging practices. It is an immersive three-dimensional (3D) virtual reality (VR) in which avatars can represent human users, interact with each other, and create artificial societies in an online environment (Díaz et al., 2020). This technology attempts to create unique networks supported by innovative digital technologies in which people can be immersed in interconnected experiences. It is built on a virtual complex 3D world where users, which are referred to as avatars, can interact and socialise with other users limitlessly (Kye et al., 2021). Such a virtual world is a metaphor for the real world, with individuals engaging in activities related to everyday life situations. The avatars accurately represent the users, enabling them to interact and communicate in 3D virtual environments (Schlemmer et al., 2015).

Metaverse technology was first used in gaming and socialising settings to provide users with a shared virtual space to interact in, regardless of their physical location. This use was further expanded to cover various contexts, such as in healthcare with platforms for telemedicine that healthcare professionals can use to diagnose and treat patients remotely (Chengoden et al., 2022), in business with virtual meetings, trade shows and other business-related events (Queiroz et al., 2023; Yawisedet al., 2022), in tourism with people exploring virtual versions of real-world destinations (either as a form of entertainment or as a way to plan future travel; Go & Kang, 2023; Gursoy et al., 2022; Volchek & Brysch, 2023) and in art and design with artists and designers showcasing their work and collaborating with others (Guo et al., 2023; Hwang & Koo, 2023). In educational settings, the use of the metaverse is also evident (Contreras et al., 2022; Hwang & Chien, 2022; Hwang, 2023; Lee et al., 2022; Makransky & Mayer, 2022; Mystakidis et al., 2022; Sarıta & Topraklıkoğlu, 2022; Sghaier et al., 2022; Yang & Kang, 2022). These studies suggest that the use of the metaverse in educational settings has the potential to enhance learners' experiences and outcomes by providing interactive environments that facilitate active engagement with course content and learning through discovery and collaboration (Usman, et al., 2022).

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Recent studies have focused on providing a comprehensive and critical evaluation of existing research on the use of the metaverse in education to gain a deeper understanding of the current state of knowledge on the topic (Alfaisal et al., 2022; López Belmonte et al., 2023; Saritas & Topraklikoglu, 2022; Samala et al., 2023). These studies demonstrate the metaverse's potential to facilitate a transformative shift in education and enhance students' motivation and engagement. The use of metaverse in academia refers to enabling educators to be virtually immersed with learning experiences that go beyond what is achievable in conventional classrooms. Such unique experiences are realistic and interactive which are characterized by a service-oriented approach with sustainable materials and social implications (Boulton et al., 2018). The scalable environment of the metaverse enables large-scale interaction and enhances social crowds (Suzuki et al., 2020). This would provide a more engaging educational experiences, cater to individual learning styles, and reach a wider audience. This has also resulted in developing numerous attractive applications supported by metaverse technology including Roblox which exceeded more than 42 million active players (Rospigliosi, 2022).

On the other hand, the potential negative impact of the metaverse on learning is contingent upon the specific context and implementation of the technology. While some studies suggest that there may be limitations to the use of metaverse environments in educational settings, such as learners experiencing disorientation or cognitive overload when navigating virtual environments or the technology being less effective in promoting certain types of learning (e.g., critical thinking or problem-solving skills), the effectiveness of metaverse in education as a learning tool remains an area of active research. It is worth noting that there is a growing body of evidence suggesting that the use of virtual environments can be highly effective in promoting learning outcomes for a variety of subject areas, including science, mathematics, and language learning (Dalgarno & Lee, 2010; Lee et al., 2010; Liuet al., 2020). The potential benefits and drawbacks of the metaverse on learning are context-dependent and merit further investigation. Thus, this meta-analysis research aims to bridge this gap by answering the following research questions:

RQ1. What is the overall effect of the metaverse on learners' performance?

RQ2. How do influencing factors (i.e., skill targeted, subject taught, educational level and technology used) moderate the effectiveness of the metaverse on learning?

This research will contribute to understanding the impact of the metaverse on education from meta-analytical perspectives and identify areas where further research is necessary. The rest of the paper is organised as follows: the next section explores the literature on the metaverse in education and the studies conducted in this area, followed by a detailed description of the methodology used and the analysis procedures. The results and a discussion of their implications are presented later, followed by the study conclusions with some suggestions for future work.

Literature Review

Metaverse and Learning Domains

The term 'metaverse' was coined by science fiction writer Neal Stephenson in his 1992 novel Snow Crash. In the book, the metaverse is a VR shared by millions of users, where people can interact with each other and virtual objects in a fully immersive and interactive environment. Second Life is often cited as one of the earliest and most successful examples of a metaverse platform. Second Life was launched in 2003 by the company Linden Lab, and it quickly gained popularity as a virtual world where users could create their own avatars, interact with others and engage in a wide range of activities. The extensively researched platform was used in various instructional contexts to enhance the learning process (Kemp & Livingstone, 2006). However, the new technological advances and increased interest in the learning domains of the metaverse have led many to re-consider its wide range of possibilities, including the virtual space that provides realistic representations of selves, which could enhance the social aspect of teaching and learning (Tlili et al., 2022). The essence of the metaverse, which makes it unique compared with other technologies, is the advent of immersive technologies it offers, such as VR, mixed reality, augmented reality (AR) and extended reality. With these features, learners can attend classes virtually, have access to elements of the real classroom and communicate through their avatars. This creates an immersive educational experience that enhances learners' opportunities and establishes space for dynamically social communication of thoughts, ideas and digital artefacts with scaffolding, high immersion, and virtualisation (Kye et al., 2021). Various learning domains have shown incredible advancement due to this promising technology, including distinguished experiences in mathematical knowledge, healthcare, medicine, and engineering. In these fields, participants can behave dynamically, such as by conducting experiments and virtual visits to appropriate sites (Huh, 2022; Reyes, 2020).

Metaverse and Skills Enhancement

Learning skills are habits that can be used and nurtured throughout life to accomplish tasks and communicate more successfully. They are classified into three categories: cognitive, affective and effective skills. Cognitive skills refer to mental processes that involve thinking, reasoning, problem-solving and decision-making (process). They are associated with academic pursuits and involve the ability to acquire and apply knowledge and understanding (Kirschner et al., 2006). Examples of cognitive skills include critical thinking, creativity, and logical reasoning (Anderson & Krathwohl, 2001). Affective skills, on the other hand, refer to the emotional and social aspects of learning (emotions). They involve the ability to understand and manage one's own emotions and the emotions of others (Salovey & Mayer, 1990). Examples of affective skills include empathy, self-awareness, and social awareness (Martínez-Martínez et al., 2020). Effective skills refer to the practical application of knowledge associated with real-world situations (results). They involve the ability to use one's knowledge and skills to achieve specific goals and outcomes (Wiggins & McTighe, 2005). Examples of effective skills include communication, problem-solving and leadership skills. It is important to note that these three types of skills are interconnected and often work together to help individuals achieve their goals. For example, effective communication requires both cognitive and affective skills, such as the ability to understand and articulate ideas clearly and the ability to read and respond to social cues (Martínez-Martínez et al., 2020).

The metaverse has improved learners' skills and perceptions towards learning. This supports Hwang and Chien (2022), who emphasise that the metaverse can be distinguished from AR and VR with three features: shareability, persistence and decentralisation. This also confirms that the metaverse plays a key role in encouraging learners to create a more positive learning environment due to the possibilities of immersion, collaboration, and interactions, which support the development of varied social experiences. Many studies show the harmony between the metaverse and the subject under investigation, leading to higher motivation and more effective performance. For instance, Reyes (2020) designed a metaverse-oriented course using AR and mobile learning to teach mathematics.

The findings reveal that using the metaverse in mathematics results in better outcomes for students' learning. The reasoning behind this motivation is that there are numerous world types in the metaverse, such as survival, maze, multichoice, racing/jumping and escape room worlds, as reported by Park and Kim (2022). However, successful metaverse learning experiences, which could lead to more motivated learners and better performers, requires considerable attention to three factors, as reported by Lee et al. (2021). Those are digital twins, where digital models and representations of the physical world can be created and nurtured (i.e. physical environments that are synchronously used); individuals with high digital competencies, which ensure that such learners have expertise in technology; and the co-existence of physical-virtual, which involves merging and connecting the virtual and physical environment.

Experimental studies investigating the impact of integrating the metaverse in teaching and learning environments on learners' performance are limited. In Hwang (2023), the effectiveness of utilising a metaverse in maker education was investigated through empirical research. The study involved a control group and an experimental group, with the latter registering their digital artwork as an NFT (none-fungible token) displaying it in the metaverse. Both groups showed a significant statistical difference in creative problem-solving and curiosity, but only the experimental group showed improvement in creative cognition. The metaverse treatment resulted in a significant improvement to the sense of achievement and ownership of the products. The student reflections on the metaverse exhibition were positive.

During the COVID-19 pandemic, Lee et al. (2022) noticed the limited active student participation, particularly in practical classes that required both theoretical and empirical knowledge, due to the transition from traditional in-person education to remote learning. To overcome such limitations, they proposed a system that integrates VR and metaverse methods into the classroom. An aircraft maintenance simulation was developed based on the proposed system, and an experiment was conducted to compare its effectiveness with a video training method. Knowledge acquisition and retention tests were administered, and survey responses were collected to measure the sense of presence among participants. The results of the experiment showed that the group using the proposed system outperformed the video training group on both knowledge tests, and the participants reported a sense of spatial presence, indicating the appropriateness of the proposed system's usability.

The immersion principle in the metaverse is explored in Makransky and Mayer (2022), which involved 102 middle school students participating in a virtual field trip to Greenland using either a head mounted display or a two-dimensional video. The immersive group scored significantly higher than the video group in areas such as presence, enjoyment, interest and retention. A structural equation model revealed that enjoyment and interest mediated the pathways from instructional media to immediate and delayed post-test scores. These findings suggest that the metaverse can have positive effects on learning and contribute to the cognitive affective model of immersive learning. In a different context, Mystakidis et al. (2022) describe the instructional design, development and evaluation of a fire preparedness serious game, designed for elementary school teachers. The game was developed in Unity 3D with the help of the Fire Dynamics Simulator and a script to emulate and visualise fire propagation. It was then evaluated by 33 elementary school teachers in Greece using a comparative quantitative study with experimental and control groups. The results suggest that the VR serious game is appropriate for providing training, a challenge, enjoyment and mastery.

Sghaier et al. (2022) developed an intelligent system for meta-learning that is self-configurable for different users of the metaverse. A virtual learning environment was created using Open Simulator in a 3D virtual environment and connected to a learning management system (Moodle) through technology for 3D virtual environments (Sloodle). This environment allows for the management of students with different abilities and the storage of educational content. The system was tested on 50 disabled learners in a mathematics course. The results of the performance test for the mathematics course showed a significant difference ($\alpha=0.05$) in mean scores between the experimental group of disabled students, who used Sloodle, and the control group, who used traditional methods. However, the difference between the mean scores of the experimental group and the specific degree of proficiency (80%) was not statistically significant ($p>0.05$). In contrast, the mean scores of the control group using traditional methods and the specific degree of proficiency (80%) showed a statistically significant difference ($p<0.05$).

In nursing education, Yang and Kang (2022) investigated the effectiveness of a multi-access, metaverse-based nursing simulation program for early onset schizophrenia based on Raskin and Rogers' person-centred therapy. The study used a non-equivalent control group pre/post-test design, with the experimental group (n=29) using the simulation program and the control group (n=29) receiving only an online lecture on schizophrenia nursing. The experimental group showed significant improvements in knowledge, critical thinking and ability to facilitate communication compared with the control group. The researchers concluded that using the metaverse in the nursing simulation program can improve nursing students' abilities and should be adapted without spatiotemporal constraints by supplementing clinical and simulation-based practices.

Despite these positive results, researchers highlighted a gap in terms of the requirement for developing reliable tools to assess the educational outcomes produced through the metaverse. In other words, the impact of metaverse technology on learners' performance and learning outcomes needs further investigation. In the following section, we explore systematic review studies on the use of the metaverse in education to highlight further research gaps.

Metaverse and Related Systematic Reviews

A few related studies have exclusively examined the metaverse in education by adopting a systematic review approach. In one of the studies, Alfaisal et al. (2022) evaluated the metaverse research in education from information system theory/model perspectives by including 41 published studies between 2011 and 2022 using a systematic review approach. The common result of those studies deals with how university students could adopt or accept different metaverse systems in a way that would support their learning processes and boost their expertise for a better understanding of such metaverse systems. Sarıtaş and Topraklıkoğlu (2022) also conducted a systematic review to examine the studies on the use of metaverse technology in education. They found changes in the way the concept of the metaverse was applied. In the first studies on the metaverse in education, the concept was discussed in the context of 3D software, while in later studies, the concept of the metaverse began to be discussed in the context of digital reality technologies.

Samala et al. (2023) conducted a systematic review of research trends from 2012–2022 to determine the current condition of metaverse technology in education. They used the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) framework and selected 42 studies to include in their study. The findings show that research interest in metaverse technology has significantly increased in the last 10 years, peaking in 2022. Augmentation and simulation are the most prominent uses of metaverse technology in the learning process, and AR and VR are the most widely used types of metaverse technology.

In a different study, López Belmonte et al. (2023) analysed 17 studies concerned with using the metaverse in education. Those studies confirm the metaverse's potential to cause transitional advancement in education and boost students' engagement and motivation. However, they reveal a gap in designing valid instruments to evaluate the educational experiences generated within the metaverse.

Based on the current state of knowledge, no existing meta-analyses have examined the effect size of the metaverse on learners' performance. Therefore, the purpose of this meta-analysis is to fill the gap in the literature. Additionally, this study aims to investigate how various factors, such as the skills targeted, subject area, educational level and technology used, may moderate the impact of the metaverse on performance. A detailed description of the methodology employed in this meta-analysis is provided in the following section.

Method

Research Design

To answer our research questions, we conducted a meta-analysis that involves a comprehensive literature search

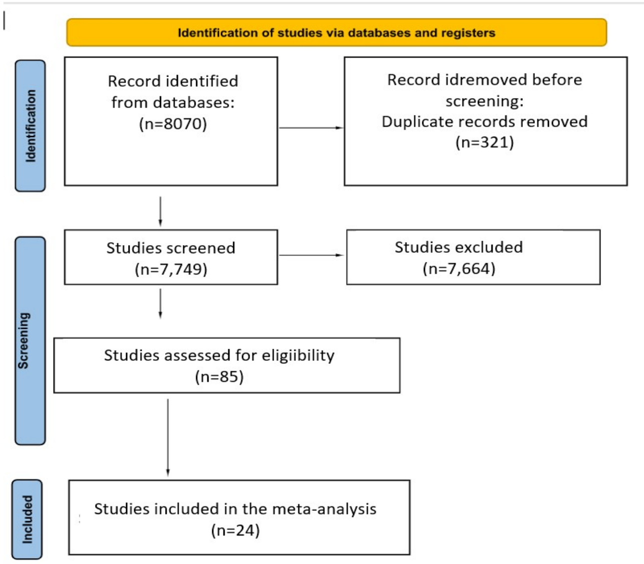

Fig. 1: Preferred Reporting Items for Systematic Reviews and Meta-analyses flowchart of screening process

of the studies that address the impact of the metaverse in instructional settings and integrating quantitative results to calculate the overall effect size (Çoğaltay & Karadağ, 2015). The aim of meta-analysis studies is to provide evidence to support or reject a specific hypothesis. The method offers a methodical and quantitative way to summarize the results from a group of investigations, which are commonly known as primary studies. By combining data from multiple sources, a meta-analysis aims to give a more thorough and accurate estimate of the impact size or result of interest. There are some ways to make sure about the smoothness of conducting meta-analysis. One of these ways is using PRISMA.

The PRISMA was used to ensure that the meta-analysis is conducted in a clear and transparent manner to improve the quality and reliability of the research. This meta-analysis included five steps: (1) conducting a comprehensive literature search, (2) selecting suitable studies by applying inclusion criteria, (3) extracting relevant data from each study, (4) evaluating the quality of the studies using the Bias tools and (5) conducting statistical analyses to calculate the overall effect size, confidence intervals and heterogeneity. A description of the stages is presented next.

Data Collection Techniques

A comprehensive literature search was performed to identify relevant studies for inclusion in the meta-analysis. Several databases were explored, such as Google Scholar, ERIC, Web of Science and SCOPUS. The search was refined using the search tools to include only studies conducted between 2020–2023. The search terms included metaverse, metaverse in education, metaverse AND learning, metaverse AND students, metaverse

Effect Size Calculation

Effect sizes based on Hedge's g were utilised in this meta-analysis to illustrate how well the metaverse improved learning. Hedge's g assesses the difference between two independent means in terms of standard deviation units and is defined as the difference between the two means divided by a standard deviation for the data (Borenstein et al., 2009). Using fundamental descriptive statistics, Hedge g was calculated (i.e. sample size, mean scores and standard deviations of the control and treatment groups). To do so, Hedge's g was chosen because it corrects small sample bias, while Cohen's d might overestimate the effect size, particularly for small samples (Lipsey & Wilson, 2001). A quantitative meta-analysis makes use of a statistic called the effect size, which is characterised as large (g=0.8 or above), medium (g=0.5–0.79), small (g=0.2–49) or of no practical importance (less than 0.2). This study also used the random-effects model, which is used in many studies in the field of language learning because the effect size varies from one study to another (Borenstein et al., 2009). The data were analysed using comprehensive meta-analysis software (Borenstein et al., 2005).

Publication Bias

The publication bias was analysed, as shown by the funnel plot (Figure 1). Figure 1 illustrates the two components of the funnel plot. Initially, most of the black patches and data points tended to symmetrically spread around the mean effect size on both sides along the 95% CI line. We used the trim-and-fill method created by Duval and Tweedie (2000) to evaluate the impact of the publication bias on the overall effect magnitude. Trim-and-fill removes the most extreme effect sizes from the positive side of the funnel plot using an iterative process. With each iteration, the effect size is recalculated until the funnel plot is symmetrical with the new effect size (Borenstein et al., 2009). The Figure 2 funnel plot has black circles for studies that were 'trimmed and filled' to obtain a symmetric distribution (Lipsey & Wilson, 2001). Two studies in this example produced a symmetric distribution, ruling out any potential publication bias and indicating that publication bias or outliers were not significant problems. Yet, it is crucial to note that publication bias is merely one of the factors that could cause funnel plot abnormalities. Others include the sample's heterogeneity. The funnel plot not only determines whether publication bias exists but also shows how close the observed mean is to the actual population mean.

To better deal with the assessment of publication bias, Fail-safe N test and Egger's regression test were used. Egger's test is designed to identify asymmetry in the funnel plot, a graphical representation of the relationship between the effect size (typically the standardized effect size) and a measure of study precision (usually the inverse of the standard error). In a balanced set of studies, the points on the funnel plot should be roughly symmetrical around the estimated effect size. Egger's test examines whether the regression intercept significantly deviates from zero. If the intercept is significantly different from zero, it suggests funnel plot asymmetry, which may be indicative of publication bias. In this meta-analysis, the intercept was 8.75. The p-value associated with the regression intercept is used to assess the statistical significance of any funnel plot asymmetry. A low p-value (typically below a chosen significance level, such as 0.05) suggests the presence of publication bias. In this meta-analysis, the p-value is 0.000. Both intercept and p-value indicate publication bias.

Additional test was used (i.e., fail-safe N). It aims to estimate the number of additional non-significant or null studies that would need to exist but were not included in the analysis to nullify the observed statistically significant effect. If the calculated fail-safe N is large, it suggests that a substantial number of unpublished or missing studies with null results would be required to negate the observed effect. However, it's important to interpret fail-safe N results with caution, as it provides only an estimate and assumes that all missing studies are non-significant, which may not be the case in reality. In this meta-analysis the z-value of observed studies was 13.47 and the p-value of observed studies was 0.000. In sum, the two tests (Egger's test and fail-safe N) revealed that there was a publication bias. Therefore, the generalization of this meta-analysis should be used with caution.

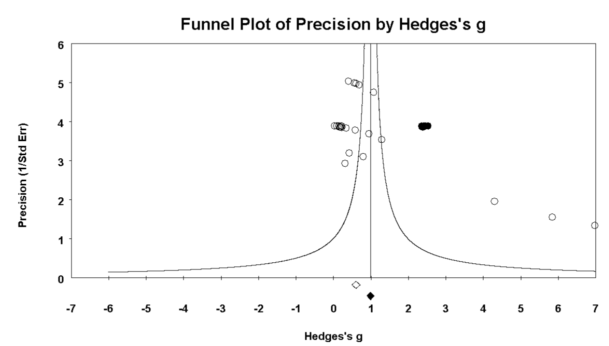

Fig. 1: Funnel plot of publication bias

Findings

These studies were analysed across several categories. Initially, the metaverse's general effect on learning was addressed. Then, factors that might have an impact on learning were examined.

The Overall Effect of Integrating Metaverse in Learning

The overall effect sizes of six studies with 23 effect sizes are shown in Table 1.

The outcome measure used in the analysis was the standardised mean difference. Table 1 demonstrates that employing the metaverse generally has a large effect size (d=0.94) on learning. The I^2 statistic and Q-test for heterogeneity are also presented. The study comprised a total of six studies with 23 effect sizes. The range of the confidence intervals was 0.591 to 1.3. As a result, the average result was considerably different from zero. The results seemed to be heterogeneous, according to the Q-test (Q=229.68, p=0). This result indicated that the metaverse is an effective tool used for learning. The analysis is also provided by the forest plot (Figure 2).

Further details concerning the variables that affect the use of the metaverse on learning were examined, and the analyses of these studies were performed according to different categories.

The Impact of Other Factors on Effectiveness of Metaverse in Learning

The first variable is the skill targeted in these studies, which are classified into three categories: cognitive, affective, and effective. The results shown in Table 2 indicate that the metaverse measurement for cognitive skills had a large effect size (g=0.98), while the metaverse used for affective skills had a small effect size (g=0.45). Effective skills were reported to have a large effect size (g=1.31). Confidence intervals were positive inside the classroom. The confidence intervals did not include zero in all categories. The Q-test showed a statistical significance (Q=6.66, df=2, p=0), indicating that the effect sizes differed significantly between the three categories.

Table 1

*N**		*Confidence intervals*		***P-value*	*Q-value*	*df*	*I2*	*G*
	*k**	*Lower limit*	*Upper limit*					
6	23	0.591	1.302	0	229.687	22	90.422	0.947

The overall effect of using the metaverse on learning

*Note: N=number of studies, k=number of effect sizes calculated.

***The level of significance is 0.05.*

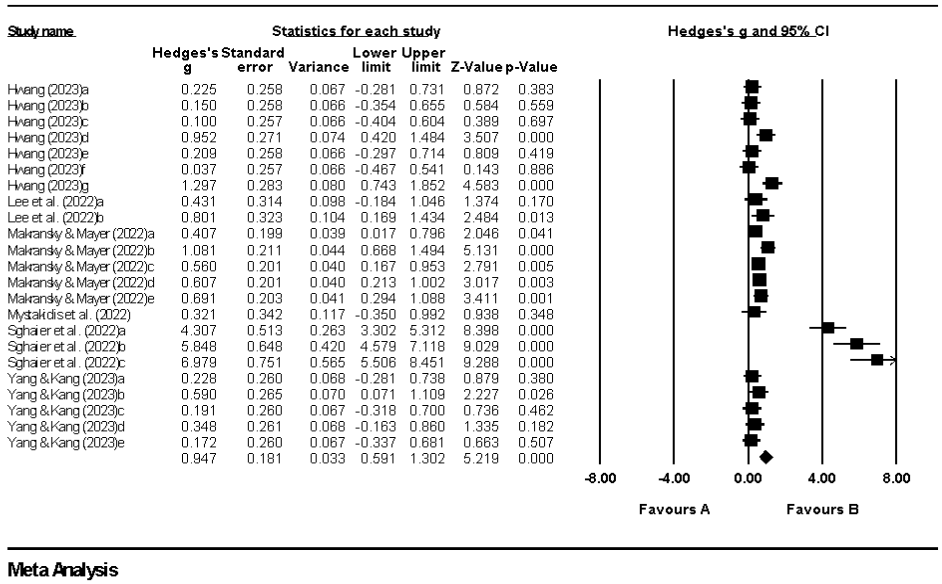

Fig. 2: Forest plot of the overall effect size of the metaverse on learning

Table 2

Variable	*k**	*G*	*Confidence intervals* *Lower limit*	*Upper limit*	*P-value*	*Q-value*	*df*
Cognitive	5	0.982	0	1.965			
Affective	6	0.458	0.173	0.744	0	6.662	2
Effective	12	1.312	0.701	1.923			

Skills measured

k=number of effect sizes calculated

The second variable is the subject taught in the studies, which are classified into two categories: social sciences and applied sciences. The results shown in Table 3 indicate that the use of the metaverse in teaching subjects related to social sciences had a small effect size (g=0.414). However, the effect size when teaching subjects related to applied sciences was large (g=1.24).

The confidence intervals did not include zero in all categories. The Q-test showed a statistical significance (Q=7.19, df=1, p=0), indicating that the effect sizes differed significantly between the two categories (Table 3).

The third variable, educational level, is classified into two categories: schools and universities. The results shown in Table 4 indicate that the use of the metaverse by learners at schools had a large effect size (g=2.309). The effect size for learners studying at universities was small (g=0.389). The confidence intervals did not include zero in all categories. The Q-test showed a statistical significance (Q=15.89, df=1, p=0), indicating that the effect sizes differed significantly between the two categories (Table 4).

The fourth variable is the technology used in these studies, which are classified into three categories: VR, simulations/3D and HMD. The results shown in Table 5 indicate that the use of the metaverse by learners who used VR had a small effect size (g=0.404). The effect size for using simulations was large (g=1.82). The effect size for using HMD was medium (g=0.66). The confidence intervals did not include zero in all categories. The Q-test showed a statistical significance

Table 3

Variable	*k**	*G*	*Confidence intervals* *Lower limit*	*Upper limit*	*P-value*	*df*	*Q-value*
Social sciences	7	0.414	0.063	0.765			
Applied sciences	16	1.24	0.749	1.731	0	1	7.196

Effect of subject

k=number of effect sizes calculated

Table 4.

Variable	k*	G	Confidence intervals		P-value	df	Q-value
			Lower limit	Upper limit			
University	15	0.389	0.21	0.567	0	1	15.895
School	8	2.309	1.382	3.237			

Effect of education level
k=number of effect sizes calculated

Table 5

Variable	k*	G	Confidence intervals		P-value	df	Q-value
			Lower limit	Upper limit			
VR	8	0.404	0.09	0.717			
Simulations	10	1.822	0.884	2.759	0	2	8.292
HMD	5	0.663	0.446	0.88			

Effect of technology used
k=number of effect sizes calculated

(Q=8.29, df=2, p=0), indicating that the effect sizes differed significantly between the three categories.

A discussion of these results is presented in the next section.

Discussion

The objective of this study is to investigate how the metaverse impacts learners' performance. What sets this research apart from previous studies is its use of a meta-analysis design, as opposed to the systematic review approach used in earlier research. In response to the first research question on the overall effect of the metaverse on learners' performance, the results show that learners who used the metaverse scored higher than learners trained using other instructional approaches. The results also revealed that the metaverse has a large effect on learners' performance. Such a positive effect is consistent with Oh et al. (2023), who found a reciprocal association between the number of friends in the metaverse and a greater social presence in the metaverse (β=0.269, p=0). Mystakidis (2022) introduced a metaverse course to reinforce learners' interest and engagement in distance learning for higher education settings.

The findings show that those learners reached high levels of engagement in metaverse platforms, and the gamified elements increased their interest, motivation and autonomy for better academic engagement. Lee and Hwang (2022) also expressed how the metaverse could provide more innovative ideas for a positive learning transformation, which could be achieved by creating digital textbooks based on a metaverse design. In fact, metaverse could be adopted as one application of e-learning and evidence for the existence of digital literacy to promote the skills of 21st century learning and education 4.0 which empower students and teachers to be connected virtually (Puniatmaja, et al., 2024).

Despite the evident positive impact on learners' performance, it is important to look deeper at the effect size of the factors related to that impact. Therefore, the second research question explored the effect of different variables on using the metaverse in learning. First, we looked at the learning skills targeted in these studies. The analysis revealed that the impact of the metaverse on learners' cognitive and affective skills had a large effect size. As discussed earlier, cognitive skills involve mental processes, such as thinking, reasoning, problem-solving and decision-making, which are necessary for academic success. Effective skills, on the other hand, refer to the practical application of knowledge and skills in real-world situations. These involve the ability to use one's knowledge and skills to achieve specific goals and outcomes. Educational metaverse environments have been shown to enhance such skills by providing learners with opportunities to engage in problem-based learning, simulations and role-playing activities (Aslan & Duruhan, 2021). These activities can help learners develop and apply their cognitive skills in a safe and controlled environment.

According to Wåhlström and Sun (2022), simulations requiring learners to make decisions under time pressures or in high-stress situations can enhance their decision-making and reasoning skills. Additionally, learners can collaborate with others in educational metaverse environments to develop solutions for complex, real-world problems and enhance their problem-solving and decision-making skills (Shu & Gu, 2023; Son et al., 2022). Furthermore, educational metaverse environments offer learners access to a wealth of information and resources, which can enhance their knowledge and understanding of various subjects. By interacting with this information in engaging ways, learners can develop their cognitive and practical skills in areas such as critical thinking, problem-solving and decision-making (Liu et al., 2020).

On the other hand, although many researchers (Bower et al., 2017; Lee & Kim, 2019) argue that metaverse environments have the potential to enhance affective skills (i.e. emotional and social skills), by providing learners with opportunities to engage in collaborative learning and develop social and emotional competencies in a virtual environment, this study revealed that the impact of the metaverse on learners' affective skills has a small effect size. One possible reason for these results can be linked to the concern that the metaverse may lead to a reduction in face-to-face interactions, which could potentially impact the development of social skills. However, research suggests that this is not necessarily the case. For example, some studies have found that virtual collaboration can enhance face-to-face communication skills (Hertel et al., 2005; Kim & Lee, 2018). Thus, additional empirical research is necessary to examine the impact of educational metaverse environments on the affective skills of learners. However, there is no clear evidence to suggest that the impact of using the metaverse to teach applied sciences is stronger than the impact of using the metaverse to teach social sciences. The impact of educational metaverses on learning outcomes is likely to depend on a variety of factors, including the nature of the subject matter, the design of the learning environment, the type of assigned tasks and the characteristics of the learners.

The subject taught was also a focus of the analysis. We looked at the effect size when using the metaverse to teach applied science subjects, such as engineering or medicine, compared with social science subjects. The findings of the studies conducted on applied sciences indicate a larger effect size in comparison with the studies conducted on social sciences, which demonstrated a smaller effect size. Some recent studies suggest that educational metaverses may be particularly effective for teaching applied sciences due to their ability to provide learners with opportunities to engage in hands-on, experimental learning. It seems that the immersive nature of the metaverse may be particularly effective for teaching applied sciences, in which learners need to engage with practical, hands-on learning.

Social sciences may also benefit from the use of educational metaverses in different ways. For example, a study by Lee et al. (2020) found that a metaverse-based social emotional learning program was effective for enhancing learners' social presence, empathy, and motivation. This suggests that educational metaverses may be particularly effective for teaching social skills and affective competencies in social science contexts. Yet, more research is needed to compare the impact of using the metaverse in teaching applied versus social sciences. The effectiveness of educational metaverses is likely to depend on a variety of factors, including learners' prior knowledge, skills, and experience. Learners at different academic levels may have different needs and learning objectives, which may affect the way they interact with educational metaverses and the impact of those technologies on their learning outcomes.

The impact of the educational level was examined in this meta-analysis, and the findings revealed a significant effect size for implementing metaverses in K–12 school settings, whereas a smaller effect size was observed when integrating metaverses in university settings. Many scholars suggest that learners at the elementary or secondary levels may benefit from educational metaverses that provide interactive and engaging learning experiences to help them develop basic cognitive and affective skills, such as problem-solving, collaboration and empathy (Suh & Ahn, 2022). In contrast, learners at the undergraduate or graduate level may benefit from educational metaverses that provide more advanced and specialised learning experiences, such as simulations and virtual laboratories that allow them to apply and test their theoretical knowledge in practical and realistic settings (Liu et al., 2020).

Learners at different academic levels may have different levels of technological proficiency and familiarity with educational metaverses. Learners who are more comfortable with technology may be more likely to engage with and benefit from educational metaverses, while learners who are less comfortable with technology may require additional support and guidance to effectively use these tools (Jeong & Kim, 2023).

Finally, the analysis involved a fourth variable, the technology used in these studies, which was classified into three categories: VR, simulations/3D and HMD. The results indicated that the use of VR had a small effect size compared with the use of simulations and HMD. The preference of simulations/3D has increased, as it is closest to reality, which could give learners a chance to practise real-time responses. HMD has become very effective, as it supports what is known as 'real-world isolation'. Simulations attempt to synthesise all five senses, rather than just what the participants might experience. Caluya et al. (2022) show that HMD-based simulations lead to better training and higher stimuli among trainees. The inclusion of Sghaier et al. (2022) may affect the mean of the overall effect size, as it reported a large effect size. Therefore, future meta-analysis needs to be conducted with more studies with the removal of outliers.

Conclusion, Limitations and Suggestions

This research examined the status of the metaverse on learners' outputs, from educational perspectives and the relevant factors which could determine its success and usefulness. The research has contributed to a further understanding of those issues, as the metaverse is considered as a recent technology that has not been fully investigated nor implemented yet in many educational settings. The metaverse is the next-generation Internet paradigm and carries promising opportunities and unlimited enablement for users, as it enables more interactive play, work, and communication in the virtual world. Many metaverse-based applications would help to establish safe and efficient learning environments for education and business. Therefore, this meta-analysis study has led to several recommendations. There is a massive need to design up-to-date curriculum and more qualified professional teachers who are willing to introduce digital learning into their classes using the metaverse. In addition, the nature of the learning environment should become more digital by factoring in collaboration, interaction, shared spaces, and group/self-reflection.

As far as the research limitations are concerned, and as with all studies, this one also has limitations. Several types of technologies are used for the metaverse, including AR, Lifelogging, Mirror world and VR. However, this research has mainly focused on VR, simulation and HMD due to their ambiguous and intermingled distinctions. It is crucial to appropriately optimise each metaverse technology according to its main purpose, the nature of the tasks and the class target. The studies included in this research topic are still limited due to the shortage of practical studies already conducted on this topic. In other words, there is no adequate prior research, due to the novelty of the topic, which makes it more difficult to find quality articles, books/book chapters or conference presentations that draw on the topic under investigation. In addition, there is still no robust clear-cut definition between what can and cannot be considered metaverse and what can and cannot be included in metaverse-oriented studies. The inclusion of more international comprehensive research and various learning experiences related to meta-learning could provide more robust understanding about this groundbreaking research area. It is expected that metaverse could reshape the traditional learning ecosystem with emphasis on a virtual learning environment and additional technologies such as open simulators. Giving such technologies to be embedded together would allow the management of students in more effective ways, especially those with individual differences or learning difficulties.

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Appendix A. Coding of the Primary Studies.

Study	*Skill*	*Subject*	*Educational level*	*Technology used*
Hwang (2023)a	1	1	1	1
Hwang (2023)b	1	1	1	1
Hwang (2023)c	1	1	1	1
Hwang (2023)d	3	1	1	1
Hwang (2023)e	2	1	1	1
Hwang (2023)f	3	1	1	1
Hwang (2023)g	3	1	1	1
Lee et al. (2022)a	3	2	1	2
Lee et al. (2022)b	3	2	1	2
Makransky & Mayer (2022)a	2	2	2	3
Makransky & Mayer (2022)b	2	2	2	3
Makransky & Mayer (2022)c	2	2	2	3
Makransky & Mayer (2022)d	3	2	2	3
Makransky & Mayer (2022)e	3	2	2	3
Mystakidis et al. (2022)	3	2	1	1
Sghaier et al. (2022)a	1	2	2	2
Sghaier et al. (2022)b	3	2	2	2
Sghaier et al. (2022)c	3	2	2	2
Yang & Kang (2023)a	3	2	1	2
Yang & Kang (2023)b	1	2	1	2
Yang & Kang (2023)c	2	2	1	2
Yang & Kang (2023)d	3	2	1	2
Yang & Kang (2023)e	2	2	1	2

Notes:
Skills: 1=Cognitive (process) 2= Affective (emotions) 3= Effective (results)
Subject 1= Social sciences 2= Applied sciences
Educational level: 1= University 2= Schools
Technology used:1= VR 2= Simulation program/3D, 3= HMD

Appendix B. Variables of the Study.

Main category	*Variable*	*Description*
Skills measured	Cognitive	The mental processes involving thinking, reasoning, problem-solving and decision-making (process)
	Affective	The emotional and social aspects of learning (emotions).
	Effective	The practical application of knowledge associated with real-world situations (results).
of education level	School	K-12
	University	Higher education
Technology used	VR	It employs pose tracking and a 3D near-eye displays to give an immersive feel of a virtual world.
	Simulations	It represents a universe in which the digital/virtual world and the real world are combined.
	HMD	It is a display device, worn on the head or as part of a helmet that has a small display optic in front.