Meta-analysis of the Effect of the Integration of Immersive Technologies on Learning in Primary Education

Metaanálisis sobre el efecto de la integración de tecnologías inmersivas en el aprendizaje en educación primaria

Meta-análise sobre o efeito da integração de tecnologias imersivas na aprendizagem no ensino básico

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Abstract

Immersive technologies such as augmented reality and virtual reality have progressively gained research interest in education. Although they have been around for a few decades, their integration into classrooms has recently become feasible due to the decrease in associated costs and the development of high-quality displays. To determine the effect of immersive technologies on academic achievement, this study conducted a meta-analysis, following PRISMA statement guidelines for the article search and using the MAJOR module of the JAMOVI software for data analysis. The search was performed in the Web of Science, Scopus, and ERIC databases, covering the period between 2018 and 2023. The sample consisted of 18 articles that met the established inclusion criteria. The results show significantly higher learning when immersive technologies are integrated, as opposed to traditional strategies. Future research should examine the effect of technologies on attitudes towards learning, emotions, academic engagement, and 21st century skills.

Keywords:
augmented reality, virtual reality, learning, academic achievement, primary education.

Resumen

Las tecnologías inmersivas como la realidad aumentada y la realidad virtual tienen un progresivo interés de investigación en educación. Si bien existen desde hace algunas décadas, recientemente han sido alcanzables para su integración en las aulas, por la disminución del costo asociado y el desarrollo de pantallas de alta calidad. Para determinar el impacto de las tecnologías inmersivas en el rendimiento académico, esta investigación efectuó un metanálisis siguiendo lineamientos de la declaración PRISMA para la búsqueda de artículos y utilizando el módulo MAJOR del software JAMOVI para el análisis de datos. La búsqueda se realizó en las bases Web of Science, Scopus y ERIC, considerando el período de 2018 a 2023. La muestra consistió en 18 artículos que cumplieron los criterios de inclusión establecidos. Los resultados evidencian un aprendizaje significativamente más alto en la integración de tecnologías inmersivas a diferencia de las estrategias tradicionales. Futuras investigaciones podrían indagar en el impacto de las tecnologías sobre las actitudes hacia el aprendizaje, las emociones, el compromiso académico y las habilidades para el siglo XXI.

Palabras clave:
realidad aumentada, realidad virtual, aprendizaje, rendimiento académico, educación primaria.

Resumo

Há um interesse cada vez maior em pesquisar as tecnologias imersivas, como a realidade aumentada e a realidade virtual, no âmbito da educação. Embora existam há várias décadas, tornaram-se recentemente acessíveis para sua integração nas salas de aula devido à diminuição dos custos associados e ao desenvolvimento de telas de alta qualidade. Para determinar o impacto das tecnologias imersivas no desempenho acadêmico, esta pesquisa realizou uma meta-análise seguindo as diretrizes da declaração PRISMA para encontrar artigos, utilizando o módulo MAJOR do software JAMOVI para a análise de dados. A busca foi realizada nas bases de dados Web of Science, Scopus e ERIC, considerando o período de 2018 a 2023. A amostra foi composta por 18 artigos que atenderam aos critérios de inclusão estabelecidos. Os resultados mostram uma aprendizagem significativamente maior na integração de tecnologias imersivas em comparação com as estratégias tradicionais. Futuras pesquisas poderiam investigar o impacto das tecnologias nas atitudes em relação à aprendizagem, nas emoções, no envolvimento acadêmico e nas competências do século XXI.

Palavras-chave:
realidade aumentada, realidade virtual, aprendizagem, desempenho acadêmico, ensino básico.

Introduction

The current technological disruption prompts a reevaluation of teaching models rooted in epistemological traditions. Various authors have addressed the challenge of adapting education to the technological era through a student-centered focused on the development of 21st-century skills For example, Siemens (2004) proposes connectivism, which emphasizes networking, knowledge management, and the ability to connect and access diverse sources of information. Prensky (2013), for his part, presents the pedagogy of co-association that suggests how, where and when teachers should employ technology.

Technologies such as Artificial Intelligence, the metaverse, robots, 3D printing, augmented reality and virtual reality are transforming how students learn and access knowledge. The integration of these disruptive technologies into classrooms must be supported by sound learning theories or approaches to ensure their effectiveness in achieving educational goals (Lui *et al*., 2023; Qiu *et al*., 2023). In addition to the previously mentioned connectivism and co-association, there are other pedagogical approaches that can also underpin the integration of technologies such as experiential learning (Kolb, 1984), multimedia learning (Mayer, 2005) and mobile learning (Sharples *et al*., 2010).

This study focuses on immersive technologies such as augmented reality (AR) and virtual reality (VR) in primary education. These disruptive technologies are renewing the way students experience physical and virtual environments, from observation to immersion. AR visualizes the physical environment overlaid with digital content in real time and with three-dimensional registration (Cabero-Almenara *et al*., 2022), while VR displaces the user to a fully synthetic environment, which can mimic real-world properties. However, it can also exceed the limits of physical reality by creating a world in which the laws governing space, time and mechanics are no longer valid (Sandoval-Henríquez & Badilla-Quintana, 2021).

There is some empirical evidence regarding the application of immersive technologies and characteristics in primary education. For example, Huang *et al*. (2023) explored the effect of AR on computational thinking and programming skills. The results demonstrated the technology's effectiveness when used with game-based learning. Abdullah *et al*. (2022) examined the impact of AR on academic achievement, interest, and science skills. Their findings showed that technology integration grounded in inquiry-based learning was effective on all three measured variables. Sandoval-Henríquez and Badilla-Quintana (2022) described experiences of interactivity, presence, and flow after students interacted with AR and VR. The results confirmed that the integration of immersive technologies, based on experiential learning, allows student to experience reciprocal interaction with the resources, a sense of being present in the virtual world, and high levels of concentration.

Systematic literature reviews highlight the educational advantages of immersive technologies. Regarding AR, Buchner and Kerres (2023) acknowledge that the technology can be used to design effective and engaging learning environments. However, they caution that its effectiveness depends on the educational context, prior knowledge, and learning objectives. Mystakidis *et al*. (2022) argue that AR supports learning in STEM subjects, but emphasize that the integration of technologies must be supported by a learning theory. Regarding VR, Lui *et al*. (2023) indicate that the technology promotes science learning, although they highlight the importance of reducing the cognitive load imposed by immersive systems, as well as considering student characteristics when designing VR-based content. Hamilton *et al*. (2021), for their part, state that VR enables the exploration of complex and realistic content, unlike other traditional strategies such as computers and digital presentations. The authors also emphasize the importance of using appropriate instruments to measure learning, since these tools can affect the interpretation of the usefulness of the technology.

Despite being essential for the advancement of educational research, systematic reviews present a relevant limitation by not including quantitative measurements that allow for comparative evaluation of the impact of immersive technologies. Consequently, meta-analyses emerge as a more effective and comprehensive alternative, as they combine results from multiple independent studies (Fau & Nabzo, 2020).

Among recent meta-analyses in this area, Cao and Yu (2023) studied the effect of AR on attitudes, motivation, and academic achievement at all educational levels. The analysis of 28 studies reported that the technology fosters better attitudes and academic achievement compared to traditional methods. Chang *et al*. (2022) examined the impact of AR on learning at all levels of education. The analysis of 134 studies shows a medium effect size, as well as positive responses, with a stronger impact in language learning and the social sciences. Villena-Taranilla *et al*. (2022) explored the effect of VR on academic achievement in K–6 education. According to 21 studies, findings indicate that the technology promotes greater learning compared to control conditions. Additionally, brief interventions (less than two hours) are more effective than those of longer duration. Coban *et al*. (2022) analyzed the impact of VR on learning in K–12 and higher education. Based on 48 studies, the results show a small effect size in the experimental condition.

Meta-analyses have predominantly focused on higher education, particularly in fields such as medicine, nursing, and rehabilitation (Guo *et al*., 2023; Hsieh *et al*., 2025; Kim & Kim, 2023; Liu *et al*., 2023; Neher *et al.*, 2025). At this educational level, students typically specialize in specific areas of study, and immersive technologies are employed to practice technical skills within safe and controlled simulation environments. Although the evidence in this context is encouraging, further research is needed in primary education settings (Sandoval-Henríquez *et al*., 2024).

Different levels of education are associated with different stages of cognitive and psychosocial development. In primary education, which ranges from 6 to 12 years of age, students are in the stage of concrete operations in cognitive development. According to Piaget (1974), this stage is characterized by the ability to think logically about objects and events. Students can perform mental operations, such as conserving quantity and classifying objects into categories. In terms of psychosocial development, they are typically in the latency period. According to Erikson (1985), at this stage, students are eager to learn and demonstrate skills in various areas. It is a stage in which support and positive recognition can foster confidence, self-esteem, and autonomy.

The integration of immersive technologies at this level should consider students' characteristics and be used to create playful experiences that foster cognitive stimulation, curiosity, and creativity (Baba *et al*., 2022; Demircioglu *et al*., 2022; Tsai & Yu-Cheng, 2022). The scarce empirical background in primary education, the contradictory findings regarding the effectiveness of these technologies on learning, and the specific characteristics of this educational level are the motivation behind this research, which poses the following questions:

RQ1. What methodological characteristics are considered in immersive technology-based interventions with respect to the sample (nationality and age), treatment (educational content, duration of exposure to the technology, and learning model), and measurement instrument (psychometric properties)?

RQ2. What is the effect of interventions based on immersive technologies on learning, compared to traditional interventions?

The following hypothesis emerges from this second question and the reviewed background information: interventions based on immersive technologies result in significantly higher learning outcomes compared to traditional interventions.

Materials and Methods

Identification and Selection of the Study Sample

A meta-analysis was conducted following PRISMA statement guidelines to ensure a relevant and accurate search of the study topic. The process consisted of three phases: identification, screening, and inclusion (Page *et al*., 2021). In addition, recommendations for the appropriate reporting of meta-analysis results were followed (Rubio-Aparicio *et al*., 2018).

Phase 1: Identification

A search was conducted in August 2023 using the Web of Science, Scopus, and ERIC databases. The keywords and search syntax were adapted from a previous systematic review on immersive technologies in primary education (Sandoval-Henríquez *et al*., 2024). The keywords used were: "virtual reality" OR "augmented reality" AND "primary school" OR "elementary school" OR "primary education" OR "elementary education" AND "academic performance" OR "academic achievement" OR "educational performance" OR "learning" AND "quasi-experiment" OR "quasiexperimental" OR "experiment" OR "experimental" OR "intervention".

Filters were applied for year of publication (studies published between 2018 and 2023), language (Spanish and English), and access type (open access studies). After applying these filters, 42 publications were retrieved from Web of Science, 55 from Scopus, and 48 from ERIC. Of the 145 articles identified, 48 duplicates were removed.

Phase 2: Screening

A review of the titles and abstracts of the 97 studies identified in the previous phase was conducted. The aim of this process was to eliminate studies that were not directly related to the central topic. Subsequently, a full-text reading of the selected articles was performed, and inclusion and exclusion criteria were applied to determine which studies met the established requirements.

The inclusion criteria comprised quantitative studies with an experimental design that used AR or VR technologies and focused on primary education. Conversely, the exclusion criteria led to the removal of studies with qualitative or non-experimental designs, those employing technologies other than augmented or virtual reality, and those focusing on educational levels other than primary education. Additionally, studies that did not report statistics required for meta-analysis, such as mean and standard deviation, were excluded.

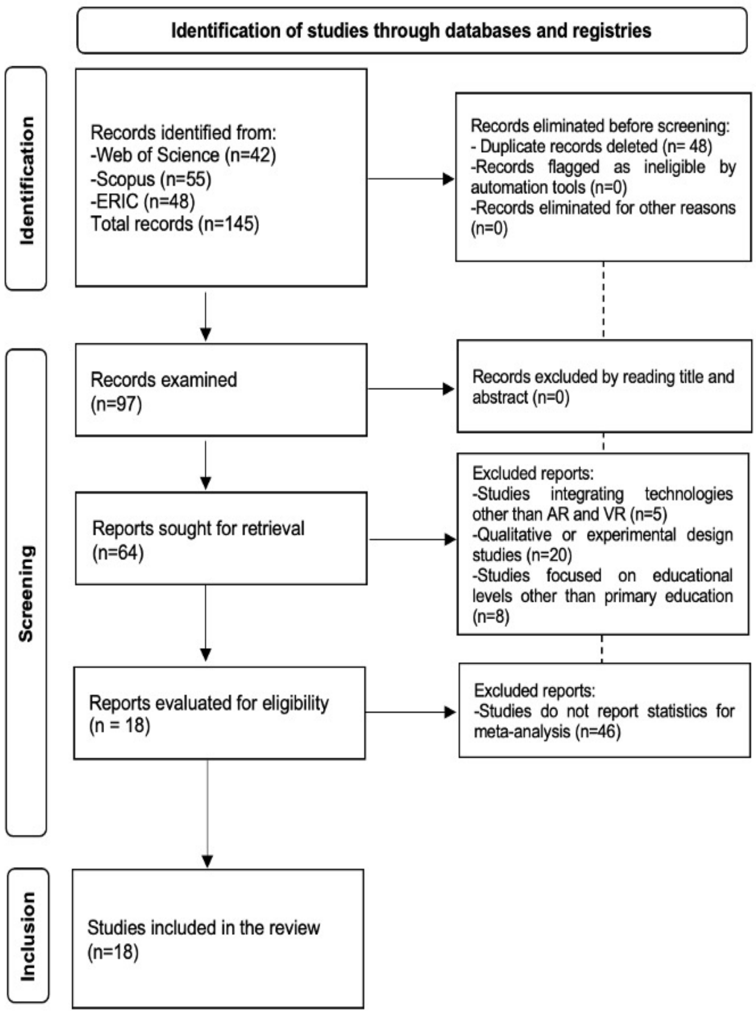
After the full-text review and application of the inclusion and exclusion criteria, a total of 79 studies were excluded.

Phase 3: Inclusion

Two investigators independently assessed the previous phases without discrepancies. The bias assessment also involved a third investigator, who used the PRISMA digital checklist (Page *et al.*, 2021) to assess the information incorporated in the manuscript sections. The management of bibliographic references and the elimination of duplicates were carried out using EndNote 21 software. Figure 1 shows the flow diagram with the phases followed.

Figure 1

Flow diagram of the article selection process



Extraction of Information from the Studies

To extract information from the 18 articles, a protocol was established that included the following elements: ID, citation, study objective, country, age, educational level, sample size, educational content, duration of exposure to technology, learning model, instrument to measure learning, and descriptive statistics. The principal investigator performed the initial extraction of information, collecting the relevant data from each article according to the established protocol. The rest of the team then reviewed and verified the extraction to ensure the consistency and accuracy of the data. Table 1 presents the extraction matrix with the information associated with each study. The results from this table will be presented to answer RQ1.

Table 1

Extraction matrix: general characteristics

ID	Citation	Study objective	Country	Educational level / age	Sample size	Educational content	Time of exposure	Learning Model	Instrument
1	Acar and Cavas (2020)	Effect of VR on academic achievement in English reading and writing	Turkey	7th grade, 12 years old	26	Reading and Writing (English)	3 weeks, 15 minutes	Experiential learning	Content test
2	Aldossari and Alsuhaibani (2021)	Effect of AR on language learning	Saudi Arabia	6th grade, 12 years old	72	Reading and vocabulary (English)	4 weeks, 2 hours per week	No report	Content test
3	Alqarni (2021)	Impact of AR on science learning	Saudi Arabia	6th grade	24	Cells (sciences)	4 weeks	No report	Content test
4	Baba *et al.* (2022)	Effect of AR on science learning	Turkey	6th grade	22	Solar system and eclipses (sciences)	3 weeks	Collaborative learning	Content test
5	Binhomran and Altalhab (2021)	Utility of AR in vocabulary learning	Saudi Arabia	6th grade, 11 and 12 years old	73	Vocabulary (English)	3 weeks	Mobile Assisted Language Learning	Content test
6	Chen *et al.* (2022)	Effect of AR on astronomical knowledge	Taiwan	5th and 6th grade	80	Solar system (sciences)	1 session, 65 minutes	Creative situated learning	Content test
7	Coşkun and Koç (2021)	Effect of AR on academic achievement	Turkey	7th grade	56	Solar system (sciences)	5 weeks	Mobile learning	Content test
8	Demircioglu *et al.* (2022)	Effect of AR on astronomy content	Turkey	7th grade, 12 and 13 years old	79	Solar system (sciences)	3 weeks, 19 hours	No report	Content test
9	Hashim *et al.* (2022)	Effect of an AR system on learning	Malaysia	10 and 14 years	38	Vocabulary (English)	5 sessions, 60 minutes	Experiential learning	Content test
10	Hsieh (2021)	Effect of AR on marine education	Taiwan	4th grade	22	Oysters (sciences)	5 sessions, 60 minutes	SMAR Model	Content test
11	Liu *et al.* (2020)	Effect of VR in science classrooms	China	6th grade, 11 years old	90	Animal world (sciences)	6 sessions, 45 minutes	No report	Content test

12	Petersen *et al.* (2020)	Effect of VR on science content	Denmark	7th and 8th grade	102	Climate change (sciences)	1 session, 60 minutes	Inquiry-based learning	Content test
13	Tsai (2020)	Effect of AR on language learning	Taiwan	5th grade, 11 and 12 years old	42	Vocabulary (English)	4 weeks, 30 minutes per week	Mobile learning	Content test
14	Tsai *et al.* (2021)	Effect of a virtual laboratory on academic achievement	Taiwan	6th grade, 11 years old	81	Air and combustion (sciences)	1 session, 80 minutes	No report	Content test
15	Tsai and Lai (2022)	Effect of AR on programming learning	Taiwan	6th grade	42	Programming	1 session, 50 minutes	No report	Content test
16	Yildirim (2020)	Effect of AR on science learning	Turkey	7th grade	63	Cells (sciences)	4 weeks	No report	Content test
17	Yildirim (2021)	Effect of AR-based science education	Turkey	6th grade	61	Human body systems (sciences)	6 weeks	No report	Content test
18	Yildirim and Seçkin (2021)	Effect of AR on academic achievement	Turkey	6th grade	50	Solar system (sciences)	7 weeks	No report	Content test

Table 2 presents the descriptive statistics (mean, standard deviation, and number of cases) associated with each study. The results from this table will be presented to answer RQ2.

Table 2

Extraction matrix: descriptive statistics

		Posttest experimental group			Posttest control group		
ID	Citation	M	SD	n	M	SD	N
1	Acar and Cavas (2020)	67.07	21.74	15	29.27	13.12	11
2	Aldossari and Alsuhaibani (2021)	17.56	1.90	36	12.31	4.16	36
3	Alqarni (2021)	3.63	0.48	12	2.87	0.38	12
4	Baba *et al.* (2022)	20.64	3.67	11	16.64	4.01	11
5	Binhomran and Altalhab (2021)	5.00	2.18	38	4.86	2.27	35
6	Chen *et al.* (2022)	91.55	12.67	40	82.00	22.15	40
7	Coşkun and Koç (2021)	93.24	9.62	29	59.26	19.31	27
8	Demircioglu *et al.* (2022)	25.96	2.51	26	22.07	3.67	26
9	Hashim *et al.* (2022)	85.79	13.87	19	88.95	9.37	19
10	Hsieh (2021)	69.55	17.53	11	63.18	13.09	11
11	Liu *et al.* (2020)	0.70	0.22	47	0.56	0.22	43
12	Petersen *et al.* (2020)	16.54	4.6	50	16.64	4.06	50
13	Tsai (2020)	76.1	12.05	22	41.8	11.05	20
14	Tsai *et al.* (2021)	86.58	9.90	41	83.00	11.36	40
15	Tsai and Lai (2022)	91.68	1.54	22	85.75	2.48	20
16	Yildirim (2020)	77.41	21.71	31	64.21	27.06	32
17	Yildirim (2021)	78.53	22.82	30	65.32	26.07	31
18	Yildirim and Seçkin (2021)	22.69	2.61	26	20.08	2.81	24

Data Analysis

The analysis was performed using the standardized mean difference as the outcome measure, which allows for the comparison of effects across studies using different outcome scales. A random-effects model was fitted to the data, assuming that the true effects vary between studies due to differences in context, intervention design, or population characteristics (Rubio-Aparicio *et al.*, 2018).

Heterogeneity (i.e., tau^2) was obtained using the restricted maximum likelihood estimator (Viechtbauer, 2005). In addition to the estimation of tau^2, the Q-test for heterogeneity and the I^2 statistic were calculated. If some degree of heterogeneity is detected (i.e., $tau^2 > 0$, regardless of the Q-test results), a prediction interval for the true effect is also provided. Studentized residuals and Cook's distances are used to examine whether the studies may be outliers and/or influential in the context of the model.

Publication bias was assessed using the Fail-Safe N, which estimates the number of unpublished or missing studies with null or non-significant results were included; the overall results of the meta-analysis would still be statistically significant or consistent.

In addition, bias was assessed with Egger's Regression, which examines the association between effect sizes and their precision. A non-significant *p*-value (e.g., $p > 0.05$) indicates no evidence of publication bias. However, a significant p value (e.g., $p < 0.05$) suggests the presence of publication bias but may also mean that the sample size is too small, or that there is substantial heterogeneity among the included studies (Egger *et al.*, 1997).

Data analysis was performed using the MAJOR module of JAMOVI software version 2.3.13.0.

Results

The results are presented according to the research questions.

General Characteristics of the Studies (RQ1)

The studies come from Turkey (39%; $n = 7$), Taiwan (28%; $n = 5$), Saudi Arabia (17%; $n = 3$), Malaysia (6%; $n = 1$), China (6%; $n = 1$), and Denmark (6%; $n = 1$). The educational levels with the highest prevalence are 6th grade (50%; $n = 9$) and 7th grade (28%; $n = 5$). Sample sizes range from 22 to 102 participants, distributed across control (absence of technologies) and experimental (presence of immersive technologies) groups.

The interventions address educational content in science (67%; $n = 12$), English (28%; $n = 5$), and programming (6%; $n = 1$). The reported learning models include mobile learning (17%; $n = 3$), experiential learning (11%; $n = 2$), inquiry-based learning (6%; $n = 1$), the SMAR model (6%; $n = 1$), creative situated learning (6%; $n = 1$), and collaborative learning (6%; $n = 1$). Fifty percent of the studies do not report a specific learning theory guiding the integration of immersive technologies.

Exposure time is reported in two main formats: by number of weeks (61%; n = 11), ranging from 3 to 7 weeks, or by number of sessions (39%; n = 7), ranging from 1 to 6 sessions.

Regarding the instruments, the studies generally employ ad hoc content tests to measure academic achievement, mostly based on multiple-choice items (94%; n = 17). Only one study reports using a test previously developed by other authors.

Effectiveness of the Integration of Immersive Technologies (RQ2)

Table 3 presents the results of the heterogeneity test, showing significant heterogeneity among the 18 studies ($Q(17)=128.745$, $p<0.0001$), considerable variability among the effects of the individual studies ($tau^2=0.7406$) and observed variability ($I^2=89\%$), suggesting that the studies originate from different populations.

Table 3

Heterogeneity statistics

Tau	Tau^2	I^2	H^2	df	Q	P
0.861	0.7406 (SE= 0.2914)	89.78%	9.782	17.000	128.745	< .001

Table 4 presents the results of the publication bias; the Fail-Safe N indicates that at least 1,043 unfound or unpublished studies with null results would be necessary for the results of the current meta-analysis to be insignificant. For its part, the Egger's Regression test indicates that there is significant statistical evidence of asymmetry in the data. This suggests the possible presence of a publication bias, where studies with significant results are more likely to be published than those with non-significant results.

Table 4

Publication bias assessment

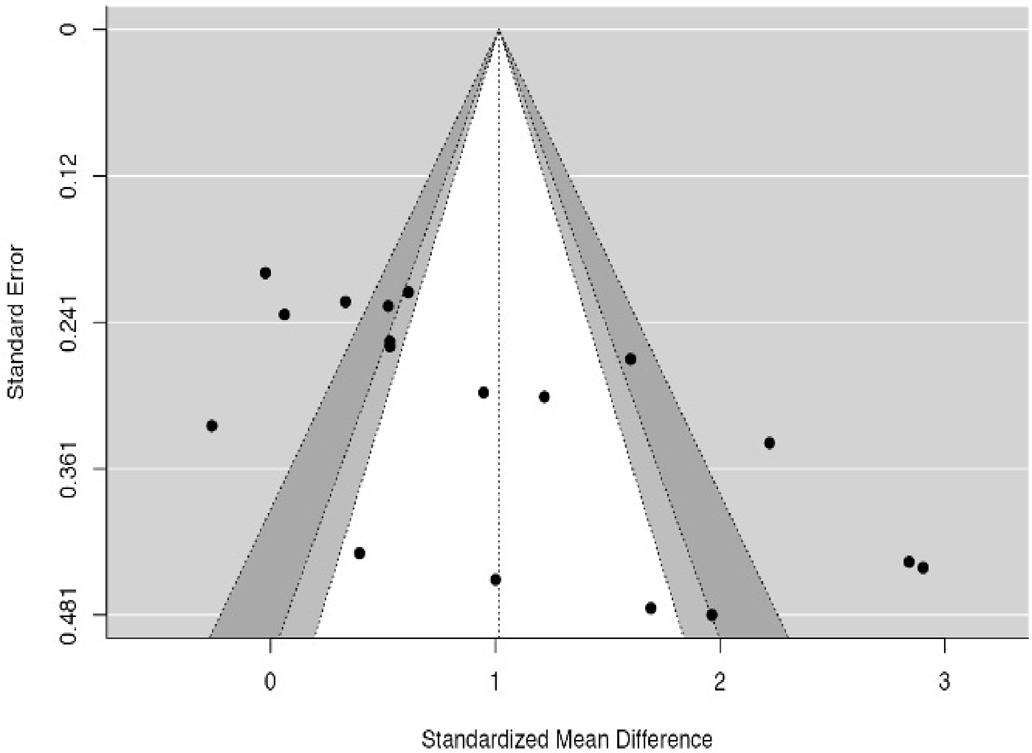
Test name	Value	P
Fail-Safe N	1043.000	< .001
Egger's Regression	3.490	< .001

Note. Fail-safe N calculation using the Rosenthal approach.

An examination of the studentized residuals revealed that none of the studies had a value greater than ±2.9913, indicating no outliers in the context of this model. According to Cook's distances, none of the studies could be considered overly influential. Figure 2 presents the funnel plot.

Figure 2

Funnel Plot



Both the rank correlation test and the regression test indicate possible skewness (p = .0022 and p = .0005, respectively), suggesting the presence of publication bias. This asymmetry may reflect a tendency to publish studies with significant or positive results, while non-significant or negative findings remain unpublished or are less accessible.

Table 5 presents the results of the random-effects model for the 18 studies. The analysis estimates a large effect size of 1.02 (Sawilowsky, 2009). However, due to variability across studies, the true population effect may range from 0.591 to 1.443, with a 95% confidence interval.

Table 5

Random-Effects Model (k = 18)

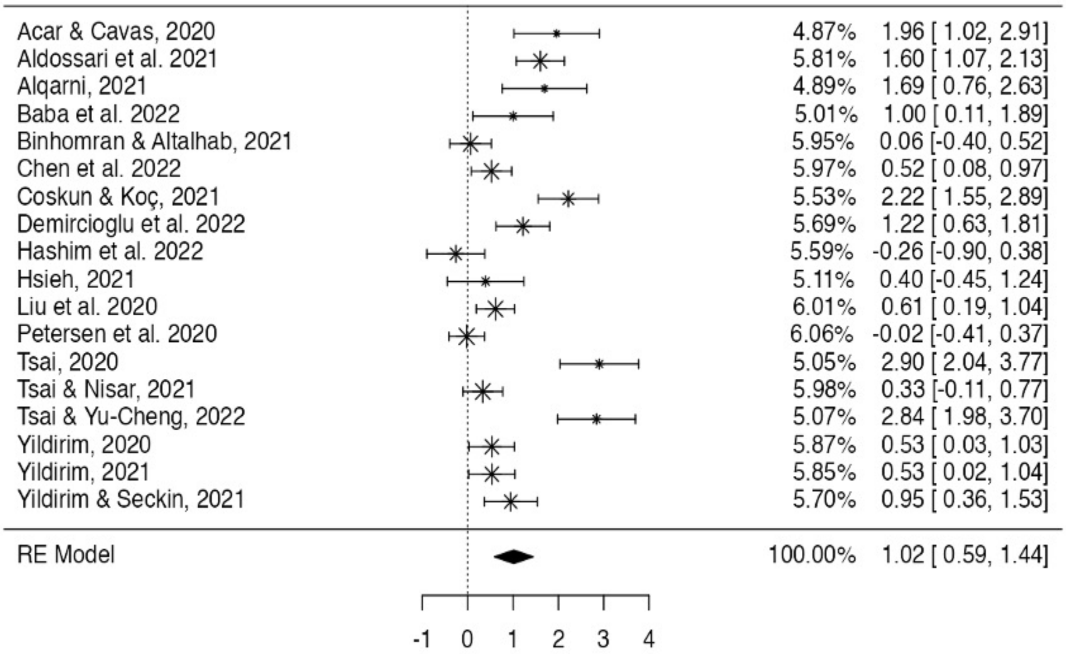
	Estimate	se	Z	p	CI Lower Bound	CI Upper Bound
Intercept	1.02	0.218	4.68	< .001	0.591	1.443

Note. Tau^2 Estimator: Restricted Maximum-Likelihood.

Figure 3 displays the forest plot, which includes 18 effect sizes, each represented by an asterisk in the central column, with horizontal lines indicating their corresponding 95% confidence intervals.

Figure 3

Forest Plot



The dashed vertical line denotes the line of no effect, while the diamond at the bottom represents the overall pooled effect size. The position of the diamond to the right of the vertical line indicates that the experimental group achieved significantly better learning outcomes compared to the control group.

Discussion

General Characteristics of the Studies (RQ1)

According to previous findings and systematic reviews (Altinpulluk, 2019; Garzón *et al.*, 2019; Qiu *et al.*, 2023), there is greater scientific production on the use of immersive technologies in Asia. This corroborates that certain countries in that region are showing increasing interest and investment in integrating technologies to enhance the learning experience in primary education.

Regarding the age of the participants, the studies were conducted with students aged 11 and 12, corresponding to sixth and seventh grades. At this stage of cognitive and psychosocial development, students are undergoing changes in how they think, process information, and understand the world, as well as in how they interact socially (Erikson, 1985; Piaget, 1974). The visualization features of AR and VR can have a significant impact on students' learning and development at this age, due to several factors identified in the literature: the exploration of concepts and scenarios in an interactive way; increased engagement in learning, as they are at an age when interest may fluctuate due to personal and contextual factors; development of cognitive and social skills; and sensory stimulation that supports different learning styles (Akçayır & Akçayır, 2017; Hamilton *et al.*, 2021; Villena-Taranilla *et al.*, 2022).

Concerning the educational interventions, the studies mainly address science-related content. This finding is consistent with other reviews that highlight the widespread use of immersive technologies for learning about cells, human body systems, the planetary system, flora, and fauna (Garzón *et al*., 2019; Pellas *et al*., 2021; Mystakidis *et al*., 2022; Oyelere *et al*., 2020). As for the time of exposure to the technology, it varies in how it is reported (e.g., weeks, sessions, hours), which constitutes a limitation. The lack of consistency in reporting exposure time makes it difficult to replicate interventions or draw generalizable conclusions. For example, the study by Hashim *et al*. (2022), which reports improvements in learning after several weeks of exposure, may not be comparable to the study by Tsai and Yu-Cheng (2022), which only reports minutes of use in a single session.

The studies apply different learning theories to the design of technology-based interventions, with mobile learning and experiential learning being the most common. However, the lack of an explicit theoretical framework in 50% of the studies analyzed is a recurring limitation in educational research (Buchner & Kerres, 2023; Mystakidis *et al*., 2022; Qiu *et al.*, 2023). Learning theories provide the conceptual basis for selecting and designing pedagogical strategies aligned with educational goals and student needs. When theories are not referenced, it becomes difficult to understand the rationale behind the integration of AR and VR in the classroom (Sandoval-Henríquez & Badilla-Quintana, 2021).

Regarding assessment, the studies employed content tests to measure academic achievement. None of the reviewed studies used indirect measures such as perceived learning. This aligns with the findings of previous reviews (Hamilton *et al*., 2021). The inclusion of indirect measures alongside traditional assessments could offer a broader understanding of the motivational, emotional, and engagement-related dimensions associated with immersive technologies and their effect on learning. Pedagogical models such as co-association also promote the use of alternative forms of assessment, such as self-assessment and peer assessment, which help students become aware of their own progress and develop self-regulation skills (Prensky, 2013).

Effectiveness of the Integration of Immersive Technologies (RQ2)

Individual studies report that the integration of immersive technologies has a positive impact on academic achievement compared to control conditions. In this regard, learning gains are a commonly reported educational benefit in previous systematic reviews (Buchner & Kerres, 2023; Garzón *et al*., 2019; Mystakidis *et al*., 2022). The results of the meta-analysis indicate an effect size of 1.02, which is considered large (Sawilowsky, 2009). However, due to variability across the 18 studies, the true population effect may range from 0.59 to 1.44 with a 95% confidence interval—i.e., a moderate to large effect.

These findings are consistent with those of other meta-analyses. Villena-Taranilla *et al*. (2022) reported a moderate effect size (g = 0.64), noting that shorter interventions (less than two hours) were associated with greater learning effects. Similarly, Chang *et al*. (2022) found a moderate effect size (g = 0.65) for the impact of immersive technologies on academic achievement. Garzón *et al*. (2019) also reported a moderate effect size (g = 0.65), with higher effectiveness observed in science, arts, and humanities. In contrast, Cao and Yu (2023) reported a significant difference between experimental and control groups, with the former achieving a large effect size (g = 0.85).

However, some meta-analyses have found more modest or inconsistent results. For example, Coban *et al*. (2022) reported a small effect size (g = 0.38) for the impact of VR on learning outcomes. Interestingly, their study also found that immersive technologies had a significantly larger effect in elementary education compared to higher education. These contrasting results underscore the need for further research that considers factors such as educational level, intervention duration, subject area, and the degree of immersion (fully immersive, semi-immersive, or non-immersive) to better understand the impact of these technologies on learning.

Conclusion

This research allows us to draw several conclusions and recommendations.

First, the hypothesis that the integration of immersive technologies leads to significantly higher learning outcomes compared to traditional strategies is supported. However, it is important to acknowledge that the effect of AR and VR may depend on additional factors, such as the quality of educational content, instructional design, and teacher training.

Second, several studies did not explicitly report the theoretical underpinnings of their interventions. It is essential for researchers to ground their work in established learning theories to ensure methodological soundness and promote the continuous improvement of educational practices. In this review, only a few theories were mentioned—such as experiential learning (Kolb, 1984), multimedia learning (Mayer, 2005), mobile learning (Sharples *et al*., 2010), and the pedagogy of co-association (Prensky, 2013). Future studies should aim to compare the effectiveness of a given learning theory when applied in both control and experimental groups. This would enable a more nuanced understanding of how the presence or absence of technology interacts with specific pedagogical frameworks in primary education.

Third, some studies showed inconsistencies in how exposure time to immersive technologies was reported. Future research should establish clearer guidelines and standards for the consistent reporting of exposure time and other key variables in experimental studies. Providing detailed information about study design enhances transparency, improves the comparability of findings, and contributes to a more robust understanding of how technology affects learning across educational contexts.

Finally, this meta-analysis has several limitations that should be taken into account. Due to the variability in how intervention duration was reported, it was not possible to compare whether longer or shorter exposure times had differential effects on academic achievement. Another limitation concerns publication bias: studies with positive results are more likely to be published than those with non-significant or negative findings. This may lead to an overestimation of the impact of immersive technologies on learning and should be carefully considered when interpreting the overall conclusions of this meta-analysis.

Notes:

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Authorship contribution:

Francisco Javier Sandoval-Henríquez: conceptualization, research design, data collection, processing and analysis of information, preparation and correction of the document.

Fabiola Sáez-Delgado: data collection, processing and analysis of information, preparation and correction of the document.

María Graciela Badilla-Quintana: data collection, processing and analysis of information, preparation and correction of the document.

Availability of data:

The dataset supporting the results of this study is available upon request from a correspondence researcher.

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