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Impact of augmented reality on learning motivation in primary and secondary education: systematic and meta-analytical review

Impacto de la realidad aumentada en la motivación para el aprendizaje en Educación Primaria y Secundaria: revisión sistemática y metaanalítica

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ABSTRACT

The incorporation of information and communication technologies (ICT) in education has facilitated the arrival of innovative didactic resources, such as augmented reality, which stands out for its ability to integrate virtual and real elements. This study aimed to explore and synthesize the effect of using augmented reality on motivation for learning among students in primary and secondary education stages. For this systematic and meta-analytical review, PRISMA guidelines were followed, using the Scopus and Web of Science databases as data sources. A total of eleven documents were analyzed to measure the motivation variable. The results indicated a favorable effect across the interventions on the four components of motivation for learning ($Z = 10.15$; $p < .00001$; $I^2 = 0$). These findings suggest that experimenting with augmented reality tools in the classroom motivates students at both educational stages to acquire new knowledge. In conclusion, the use of augmented reality has a positive influence on motivation for learning among primary and secondary students, and its implementation is therefore recommended.

RESUMEN

Palabras clave

Educación, metaanálisis, motivación, realidad aumentada, TIC.

La incorporación de las tecnologías de la información y la comunicación (TIC) en la educación ha facilitado la llegada de recursos didácticos innovadores, como la realidad aumentada, que destaca por su habilidad para integrar elementos virtuales y reales. El objetivo del presente estudio consistió en explorar y sintetizar el efecto que posee la utilización de la realidad aumentada sobre la motivación para el aprendizaje en el alumnado en las etapas educativas de Educación Primaria y Secundaria. Para la realización de esta revisión sistemática y metaanalítica se siguieron las directrices PRISMA, tomando como fuente de datos las bases de datos Scopus y Web of Science. Un total de once documentos fueron analizados en torno a la medición de la variable motivación. Los resultados indicaron un efecto favorable sobre el conjunto de intervenciones en los cuatro componentes de la motivación para el aprendizaje ($Z = 10.15$; $p < 0.00001$; $I^2 = 0$). Estos resultados indican que la experimentación en el aula con el uso de herramientas de realidad aumentada motiva al alumnado de ambas etapas educativas hacia nuevos conocimientos. En conclusión, el uso de la realidad aumentada influye positivamente sobre la motivación para el aprendizaje en los estudiantes de Educación Primaria y Secundaria, por lo que se recomienda su implementación.

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1. Introduction

In recent years, society has undergone profound transformations that have impacted both the social and educational spheres (Ho et al., 2024). The incorporation of information and communication technologies (ICT) has revolutionized education, promoting a more active and innovative learning experience (Garzon & Inga, 2023). These tools have facilitated new forms of interaction and collaboration, allowing students and teachers to explore more dynamic and personalized teaching methodologies (Shakirova et al., 2024). In this way, education becomes a space where creativity and participation are essential for the comprehensive development of students (Liu et al., 2023).

Educational institutions must adopt holistic and contemporary pedagogical approaches that integrate competency-based learning, aiming to foster active citizenship (Pavlou & Castro-Varela, 2024). This involves equipping students with functional skills in digital media (Sáez-López et al., 2019). The integration of technological resources in classrooms has made the teaching-learning process more dynamic, fostering active learning (Erbaş & Demirel, 2019). Consequently, the education system must update its tools to make content more accessible and engaging, addressing the needs of new generations (Moreno-Guerrero et al., 2020). In addition to improving comprehension, this approach encourages curiosity and interest in learning (Ciloglu & Ustun, 2023; Lampropoulos & Kinshuk, 2024).

Among emerging technologies, augmented reality (AR) has gained a prominent role in the educational field (Bölek et al., 2022), offering immersive learning experiences through mobile devices (Triviño-Tarradas et al., 2022). Its implementation enables the development of meaningful, interactive, and contextualized learning (Simón-Sánchez & Fernández-Sánchez, 2023). Although its initial applications date back to the 1990s, its popularity has recently increased due to cost reductions and improvements in the equipment required for its application (Osborne & Mavers, 2019).

Since AR is a relatively recent concept, it is essential to define it precisely. Some authors, such as Sahin and Yilmaz (2020), describe it as an interactive platform that combines virtual elements with the real world. Others, such as López-García et al. (2019), consider it an emerging technology that enhances visual perception through computational processes capable of transforming and rendering graphics in real-time.

It is important to distinguish AR from virtual reality (VR), as although both relate to virtual environments, they have distinct characteristics (Lytvynova & Soroko, 2023). While AR overlays digital information onto the physical environment, VR immerses the user in a wholly digital environment, allowing the simulation of situations that are difficult to reproduce in real life (Bork et al., 2019). AR is characterized by (a) the integration of real and virtual 3D elements, (b) real-time interaction, and (c) an immersive user experience (Phon et al., 2019). Both technologies have the potential to transform education, but their application must align with pedagogical objectives to ensure effective access to knowledge (Lin et al., 2021).

Teachers and the broader educational community greatly benefit from the possibilities that technology offers (McBain et al., 2022). Understanding the potential of AR applied to education at all levels is essential to fully leverage its advantages (Aygün & Çelik, 2024). Several authors have highlighted the multiple benefits that AR can bring to the educational field, including increased immersion, interactivity, and personalized learning, factors that enhance students' understanding and motivation (Flores-Bascuñana et al., 2020):

- *Interactivity*: It enables students to engage dynamically with content, promoting active learning.
- *Visualization of abstract concepts*: It facilitates the understanding of complex concepts by enabling the visualization of information in 3D.
- *Motivation and engagement*: Visual and technological elements capture students' attention, increasing their motivation to learn.
- *Personalized learning*: It adapts to different learning styles, allowing students to progress at their own pace and explore topics of interest. Authors such as Wang and Huang (2025) note that personalized learning is an educational approach that tailors the content, methods, and pace of instruction to the individual needs, interests, and abilities of each student.
- *Promotion of collaborative work*: It encourages group work and develops social skills among students. Mobile-assisted collaborative learning refers to the practice of meaning-making by groups of individuals in the context of a joint activity mediated through mobile computing (Ke & Hsu, 2015).
- *Access to additional resources*: It provides instant access to a wide range of information and multimedia resources, enriching the educational process.
- *Development of technological skills*: Its use helps students develop essential digital competencies for their future.

- *Simulation of practical experiences*: It simulates practical situations without the risks associated with the real world.
- *Divergent thinking*: The use of apps that incorporate AR promotes more reflective thinking.
- *Educational inclusion*: It adapts to the specific educational needs of each student. Ainscow (2025) defines inclusive education as an educational philosophy that promotes the transformation of the education system to address the needs of all students.

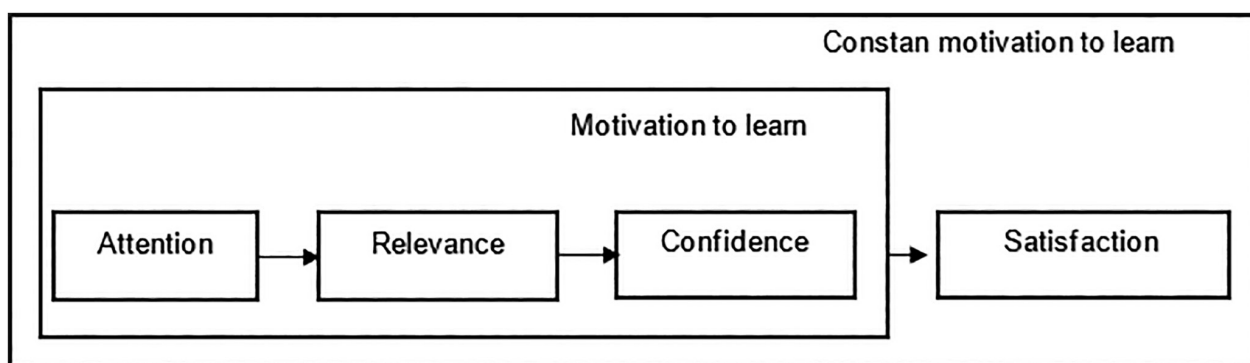
When evaluating the advantages of AR in education, its potential to transform the teaching-learning process into a more engaging and practical complementary experience becomes evident (Henssen et al., 2020). These studies have identified how AR provides a more immersive and participatory learning experience, making it a complementary tool that enhances educational effectiveness. The advantages mentioned refer to the positive aspects of AR, such as increased immersion, participation, and personalization, which contribute to making learning more effective and engaging. However, it is also crucial to consider the limitations that this technology presents, as documented in the scientific literature. Among these limitations, the following stand out (Muñoz-Cristóbal et al., 2015; Prieto, 2025):

- *Technical difficulties*: Its implementation may be interrupted by technical issues, causing frustration for users.
- *Need for detailed guides*: Clear guidelines are required; without proper guidance, users may struggle to interact effectively.
- Prior knowledge of the content and tools is crucial for their appropriate use, necessitating that students come prepared with relevant information. That is, they must have previous experience (Wang et al., 2024).

In the educational context, the implementation of activities using AR is considered an effective tool for activating positive emotions in students and enhancing their motivation, which in turn improves the outcomes of the teaching-learning process (Redondo et al., 2020). Therefore, motivation becomes a central element, as its increase leads to greater engagement, cooperation, and interest in subjects (Rueda et al., 2023), as well as higher levels of satisfaction and attention, enriching the content (Bölek et al., 2021). According to Keller (1983), motivation is related to the magnitude and direction of behavior, influencing individuals' choices regarding their experiences and goals, as well as the effort they dedicate to achieving them. It is influenced by both internal and external factors, where individuals respond within their specific context through perceptions and reflections. Other authors, such as Cheng (2017), suggest that motivation is an internal state that drives action and manifests in students' willingness to participate in class activities, as well as their reasons for doing so.

Among the main tools for measuring the motivation generated in learning is the *Instructional Material Motivational Survey* (IMMS), created by Keller (2010), based on the *ARCS Model*, which consists of the following components: Attention (this is the category or prerequisite condition for producing learning); Relevance (this category requires that students clearly understand the applicability and usefulness of what they are learning); Confidence (this relates to success and perseverance, as the combination of these two factors leads to achieving a goal); Satisfaction (this focuses on using strategies that help students feel good about the results obtained in relation to the effort put in) (Keller, 1983).

Figure 1. ARCS Model (Attention, Relevance, Confidence, Satisfaction).



Note. Taken from Keller (1983).

The ARCS Model by Keller (2010) is related to other motivational models, such as the Self-Determination Theory by Deci and Ryan (2000) and the Expectancy-Value Theory by Eccles and Wigfield (2002), as it integrates key dimensions for understanding motivation in educational contexts. While Self-Determination Theory emphasizes the fulfillment of basic needs (autonomy, competence, and relatedness) to foster intrinsic motivation, the ARCS Model translates these principles into concrete pedagogical strategies: capturing attention, establishing relevance, strengthening confidence, and promoting satisfaction. Similarly, the Expectancy-Value Theory emphasizes the impact of success expectations and the evaluation of content on motivation, aspects reflected in the confidence and relevance components of the ARCS Model. This theoretical convergence positions the ARCS Model as a practical and validated tool for designing educational interventions that enhance student engagement and performance (Deci & Ryan, 2000; Eccles & Wigfield, 2002; Keller, 1983).

Currently, there are numerous systematic review studies on the influence of ICT in education (Sijimol, 2024), and although less frequently, AR is also addressed. In this regard, Soriano-Sánchez and Jiménez-Vázquez (2023) highlight in their work that AR is an innovative resource that stimulates cognitive skills and fosters student inclusion, thereby increasing their motivation and academic performance. These findings underscore the transformative potential of AR in education and emphasize the importance of continuing to investigate its applications and benefits across diverse student populations through data analysis (Ábalos-Aguilera et al., 2024). To this end, meta-analyses provide the highest level of scientific evidence by supporting the development and review of scientific literature, combining individual results on the same research question to estimate the typical or average effect (Myung, 2023).

However, despite the points mentioned above, to date, no study has conducted a systematic review or meta-analysis that examines these aspects in an integrated manner, creating a gap in knowledge regarding the impact of Augmented Reality (AR) on students' learning motivation in Primary and Secondary Education, based on the ARCS Model.

1.1. The present study

The objective of this study is to explore and synthesize the effect of using AR on students' motivation for learning in Primary and Secondary Education. The following questions are posed:

- Question 1. Is the motivation for learning among students using AR significantly more positive in Primary and Secondary Education compared to those who do not use AR technologies?
- Question 2. Does a longer duration of intervention using AR lead to better motivation outcomes in Primary and Secondary Education?
- Question 3. Does the set of interventions using AR to enhance learning motivation show low heterogeneity?

2. Method

2.1. Sources of Information and Search Strategy

The present research is based on a systematic review of scientific literature. The guidelines proposed by the PRISMA statement (Page et al., 2021) have been followed for its implementation (Figure 2).

Figure 2. Summary of the steps to be taken in the systematic review with meta-analysis (PRISMA Statement).



The searches were conducted in July 2024 in the Web of Science (WoS) and Scopus databases, part of the Elsevier group. These electronic resources were selected because they are the most prestigious scientific databases, which include the well-known impact indexes SCImago Journal Rank (SJR) and Journal Citation Reports (JCR), respectively. The search filter used included works published in English and Spanish, as well as open-access studies. The search formula used was as follows: (((*"augmented reality"*) AND (*"motivation"* OR *"Instructional Material Motivational Survey"* OR *"IMMS"*)) AND (*"Primary* Education"* OR *"Elementary* Education"* OR *"Secondary* Education"* OR *"High* School"*))). The search was conducted across all fields of these databases.

The results obtained from each database were as follows: 147 in Web of Science and 141 in Scopus. Subsequently, the inclusion and exclusion criteria were defined (Table 1).

Table 1. Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
a) Empirical studies	a) Restricted access to publication
b) Studies that include treatment with control and experimental groups	b) Duplicate studies
c) Studies that include means and standard deviations of the control and experimental groups	c) Conference proceedings, book chapters, or books
d) The variable to be measured is motivation	d) Theoretical studies, reviews, case studies, or cross-sectional studies
	e) Language other than Spanish or English
	f) Studies that do not assess motivation using the IMMS instrument
	g) Irrelevant to the study topic
	h) Lack of sufficient information for the meta-analysis

Note. IMMS = Instructional Material Motivational Survey.

2.2. Data selection and collection procedure

The three researchers (JGSS, DJV, and SSR) independently reviewed the titles and abstracts of the identified records. They obtained and read the full texts of the preselected records. However, where there was any controversy, a comprehensive reading of the full text was conducted in order to apply the remaining established conceptual and methodological criteria. Information from the records that met the eligibility criteria was extracted into a database.

The search formula used yielded a total of 288 documents (147 in Web of Science and 141 in Scopus). Regarding the exclusion criteria, a total of 277 documents were discarded according to the established exclusion criteria, as follows: a total of 2 studies were excluded for being restricted access, in accordance with exclusion criterion a; 86 studies were excluded based on exclusion criterion b; 54 studies were excluded according to exclusion criterion c; 67 studies were excluded based on exclusion criterion d; 4 studies were excluded according to exclusion criterion e, which corresponded to 1 study published in Turkish and Portuguese, respectively, and 2 in Korean; 11 studies were excluded based on exclusion criterion f; 41 studies were excluded according to exclusion criterion g; and finally, 9 studies were excluded due to lack of results for inclusion in the meta-analysis, in accordance with exclusion criterion h.

The flowchart outlines the process followed and the scrutiny of the scientific articles, leading to the formation of the final sample (Figure 3). Ultimately, 11 studies met the eligibility criteria and were selected for review.

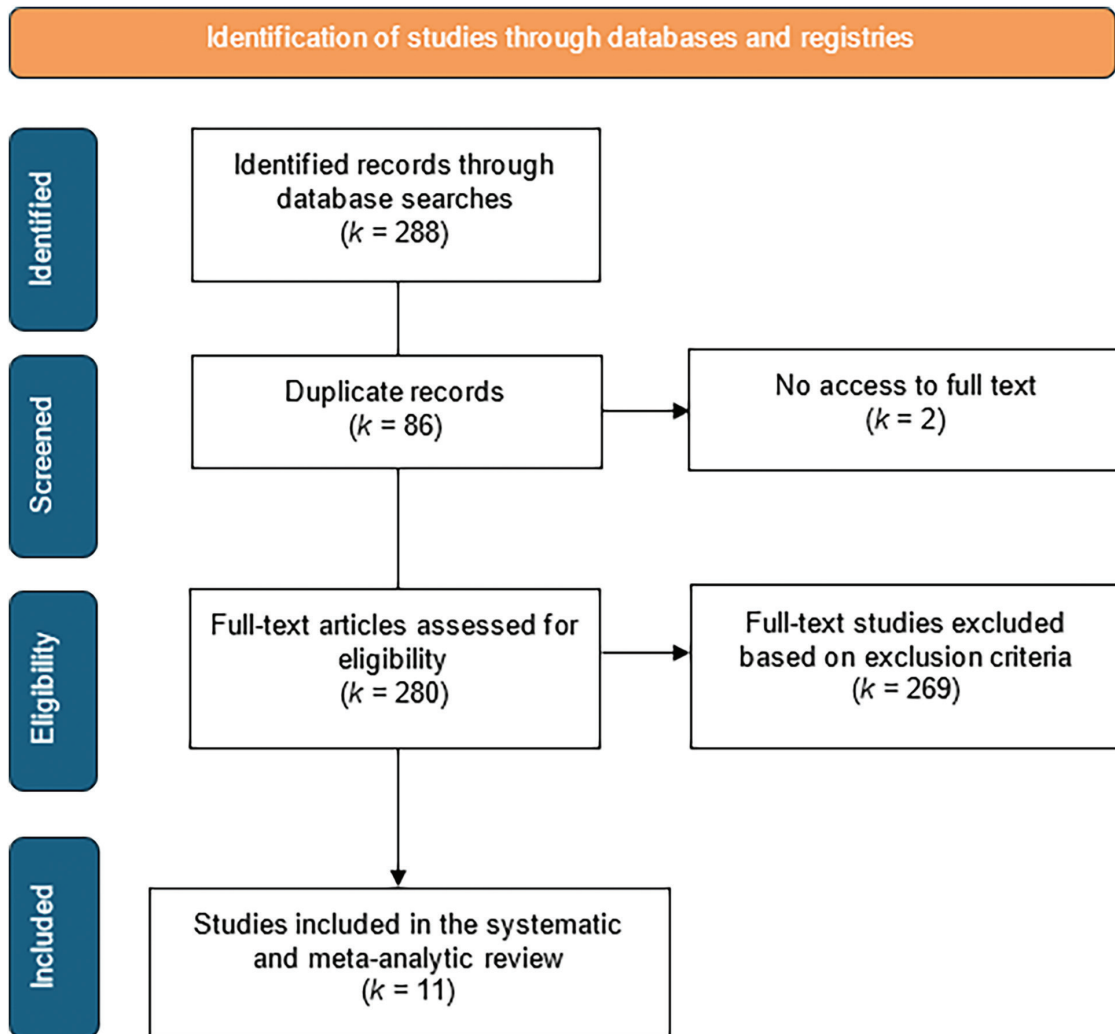
2.3. Data extraction

For data extraction, a form was designed that included information on the established inclusion criteria. These were coded following the subsequent process: (1) author(s); (2) year of publication; (3) study objective; (4) location; (5) educational stage; (6) study design; (7) participants in each group (experimental and control); (8) age range/mean age; and (9) treatment and intervention duration. With the help of this form, the most relevant quantitative and qualitative data from each of the studies were extracted. This process was carried out by the three authors, ensuring maximum reliability in information collection and resolving any controversies through a second reading of the document.

2.4. Data analysis: meta-analysis

First, the option for Intervention Review was selected to test the effectiveness of the interventions, following a *random-effects model*. The meta-analysis was conducted using the *Cochrane Review Manager* (RevMan) statistical

Figure 3. Filtering of articles from the systematic review according to the PRISMA flow (Page et al., 2021).



Source: own elaboration (2022).

software, version 5.4 (Copenhagen) (The Cochrane Collaboration, 2014), to assess the heterogeneity of the studies, effect size, data quality, etc. (Sánchez-Meca & Ato, 1989), providing a high level of evidence regarding the effectiveness of the interventions. To analyze the data, the standardized mean difference statistical method for random effects was used, as there were differences in the means of the included studies. The direction of effect sizes is considered favorable if the result indicates an improvement across the set of interventions, with significance observed through the p statistic, where the effectiveness of the set of interventions is deemed significant if $p < 0.05$. Finally, regarding heterogeneity, it is considered high if $I^2 \geq 75\%$, moderate from 50 to 75%, and low when $I^2 \leq 25\%$ (Higgins et al., 2003).

2.5. Risk of bias assessment

The risk of bias was assessed by analyzing the distribution of points in the graphs obtained from the funnel plot, following the guidelines established by Higgins et al. (2011), which suggest that an asymmetric distribution of points could indicate publication bias or methodological issues in the included studies. To ensure objectivity and accuracy in the assessment, the two researchers independently evaluated the risk of bias. Any discrepancies were resolved through a consensus meeting, thereby ensuring a thorough and precise evaluation of the risk of bias. This approach not only enhances the reliability of the analysis but also minimizes potential subjective influences in the evaluation of bias.

3. Results

The search formula and the established inclusion and exclusion criteria yielded a total of 11 studies for systematic and meta-analytic review. The most relevant qualitative results of this research are presented below.

3.1. Descriptive analysis of the selected studies

Firstly, all the studies shared a common objective of analyzing the motivation for learning through the use of AR among primary or secondary education students. Regarding the educational stage, $k = 4$ studies focused on primary education (Chen et al., 2016; Chiang et al., 2014; Hsieh, 2021; Lai et al., 2019), while $k = 7$ investigations addressed secondary education (Amores-Valencia et al., 2023; Blanca et al., 2020; Lin et al., 2021; Liu et al., 2023; Uriarte-Portillo, Blanca, et al., 2023; Uriarte-Portillo, Zatarain-Cabada, et al., 2023; Yu et al., 2022).

On the other hand, regarding the sample, it ranged from $N = 11$ (Hsieh, 2021) to $N = 162$ participants (Amores-Valencia et al., 2023). A total of $N = 404$ adolescents participated in the experimental group, and 512 in the control group. In terms of age, the studies by Chiang et al. (2014) and Hsieh (2021) reported that the children's ages ranged from 9 to 10 years, whereas the study by Amores-Valencia et al. (2023) reported that the participants' ages ranged from 14 to 17 years. All studies included both boys and girls, although some did not specify the exact number for each gender (Blanca et al., 2020; Chen et al., 2016; Chiang et al., 2014; Lin et al., 2021; Lai et al., 2019; Yu et al., 2022).

Regarding the year of publication, the oldest study was conducted in 2014 by Chiang et al. (2014), just four years after the creation of the IMMS instrument. In contrast, the topic of study has generated more publications over the years. Specifically, the last year saw the highest number of publications compared to previous years, with a total of $k = 4$ studies (Amores-Valencia et al., 2023; Liu et al., 2023; Uriarte-Portillo, Blanca, et al., 2023; Uriarte-Portillo, Zatarain-Cabada, et al., 2023).

In terms of publication location, $k = 5$ studies were published in Taiwan (Chen et al., 2016; Chiang et al., 2014; Hsieh, 2021; Lin et al., 2021; Lai et al., 2019), followed by Mexico with $k = 3$ publications (Blanca et al., 2020; Uriarte-Portillo, Blanca, et al., 2023; Uriarte-Portillo, Zatarain-Cabada, et al., 2023), and China, which had $k = 2$ publications (Liu et al., 2023; Yu et al., 2022), and finally Spain with $k = 1$ study (Amores-Valencia et al., 2023). Regarding the language of publication, all studies were published in English ($k = 11$).

Finally, in relation to the intervention time, it was the study carried out by Chen et al. (2016) which carried out a longer intervention time, since the use of AR to acquire and promote motivation for learning was throughout the course, compared to the study by Uriarte-Portillo, Blanca, et al. (2023) which, in this case, only took a total of 20 minutes (Table 2).

3.2. Synthesis of the evidence found

In Primary Education, Chen et al. (2016) designed the CMAR system, integrating AR with concept maps in the subject of Environmental Science. Students in the experimental group achieved better results than those in the other groups. Other authors, such as Chiang et al. (2014), found that using AR through mobile devices to explore animals and plants enhances students' motivation and learning. In this regard, Lai et al. (2019) indicated that the AR-based science learning system, grounded in the principle of multimedia learning contiguity, promotes scientific learning among students. Additionally, the use of picture books through the development of the AR Oyster learning system, which utilizes Unity software, enables the comprehension of digital content, including texts, images, graphics, sound effects, narration, and subtitles. This interaction with 3D models using multitouch gestures stimulates students' interest (Hsieh, 2021).

In relation to Secondary Education, the study conducted by Amores-Valencia et al. (2023) revealed that students using AR through the app *ComputAR* exhibited higher motivation, showing a strong interest in integrating this technology into the learning process. Furthermore, AR technology can be utilized as an effective learning environment to help secondary school students from both public and private institutions practice basic principles of Geometry (Blanca et al., 2020). On the other hand, Lin et al. (2021) found that students in the experimental group used the board game "Get Ahead in Medical Knowledge," which is based on scaffolding and competency. This approach allowed them to achieve greater motivation to learn, positively impacting their academic performance. Liu et al. (2023) utilized the *ArAtom software* for mobile devices and tablets, which incorporated a combination of various external representations, including texts, animations, images, and 3D

Table 2. Synthesis of the studies included in a systematic and meta-analytical review on the use of augmented reality on learning motivation in Primary and Secondary Education.

Author(s)	Year of publication	Objective of the study	Place	Educational stage	Study design	Participants in each group (n)		Age range	Treatment (intervention time)
						1	2		
Amores-Valencia et al.	2023	To analyze the influence of AR on the motivation of students at this stage, taking into account gender and previous experience with information and communication technologies	Spain	b	Instructional	159 (33.33% girls and 66.67 boys)	162 (33.33% girls and 66.67 boys)	14-17 years	AR through the ComputAR mobile app (11 sessions of 60 minutes each)
Blanca et al.	2020	Exploring the impact of AR on the motivation of Mexican public and private school students	Mexico	b	Factorial	47 (both genders but not specified)	46 (both genders but not specified)	13-15 years	AR via mobile app to ARGeo (1 session of 50 minutes)
Chen et al.	2016	To compare the effectiveness of the concept mapping AR learning material (CMAR) developed here with that of the AR learning material	Taiwan	a	Experimental	36 (both genders but not specified)	35 (both genders but not specified)	11-12 years	Mobile AR based on concept mapping (Throughout the course)
Chiang et al.	2014	Propose a mobile AR approach to conduct inquiry-based learning activities	Taiwan	a	Experimental	28 (both genders but not specified)	29 (both genders but not specified)	9-10 years	Traditional mobile AR (120 minutes)
Hsieh	2021	Propose the AR Oyster Learning System (AROLS) that integrates mobile AR with a teaching strategy for mobile education	Taiwan	a	Experimental	11 (6 boys and 5 girls)	11 (5 boys and 6 girls)	9-10 years	Traditional mobile AR (80 minutes)
Lai et al.	2019	Develop a science learning system using AR based on the contiguity principle of multimedia learning to promote students' science learning	Taiwan	a	Experimental	23 (both genders but not specified)	23 (both genders but not specified)	10-11 years	Traditional Mobile AR (180 minutes)

Table 2. Synthesis of the studies included in the systematic and meta-analytical review on the use of augmented reality on learning motivation in Primary and Secondary Education (Cont.).

Author(s)	Year of publication	Objective of the study	Place	Educational stage	Study design	Participants in each group (n)		Age range	Treatment (intervention time)
						1	2		
Lin et al.	2021	Introducing a board game board game that assimilates AR into health education	Taiwan	b	Experimental	27 (both genders but not specified)	25 (both genders but not specified)	15-16 years	Traditional Mobile AR (45 minutes)
Liu et al.	2023	Investigate the effectiveness of ArAtom on students' knowledge acquisition, learning motivation and perception of technology	Chinese	b	Experimental	47 (25 girls and 22 boys)	56 (26 girls and 30 boys)	13-15 years	Traditional Mobile AR (5 weeks with a total of 6 hours)
Uriarte-Portillo, Blanca, et al.	2023	To explore the learning effectiveness and motivational impact of using an ITS with an AR interface to practice basic principles of Geometry	Mexico	b	Quasi-experimental	25 (13 girls and 12 boys)	24 (11 girls and 13 boys)	13-15 years	AR mobile app ReAQ (20 minutes in total)
Uriarte-Portillo, Zatarain-Cabada, et al.	2023	Comparing motivation and learning outcomes of high school students in two educational settings: in the classroom and at home	Mexico	b	Factorial	53 (12 girls and 13 boys)	53 (11 girls and 13 boys)	13-15 years	Traditional Mobile AR (2 sessions of 60 minutes each)
Yu et al.	2022	To explore how different experimental conditions (AR and non-AR) may affect the learning performance and motivation of students with different levels of learning anxiety in the discipline of Physics	Chinese	b	Experimental	48 (both genders but not specified)	48 (both genders but not specified)	14-16 years	AR mobile app MagAR (3 weeks: one session per week of 40, 40 and 25 minutes, respectively)

Note: a = Primary Education; b = Secondary Education; 1 = Experimental group; 2 = Control group; AR = Augmented Reality.

models, enabling students to enhance their knowledge in Chemistry. In this regard, Uriarte-Portillo, Zatarain-Cabada et al. (2023) also report that the use of AR enables the practice of basic concepts.

Meanwhile, Yu et al. (2022) developed a mobile application based on Keller's ARCS model (1983) to promote student motivation for learning, named "MagAR." This application increased student attention and ensured that the laboratory experience had real-life implications for the students. Additionally, its use fosters motivation to learn about Geometry (Uriarte-Portillo, Blanca, et al., 2023).

3.3. Summary of meta-analytic results

The meta-analytic findings on the use of AR for motivation in primary education, with a total of $k = 4$ studies, selected a total of 98 participants for the experimental group and the control group, respectively (Table 3). Regarding the four components of motivation (attention, relevance, confidence, and satisfaction), the results indicated low heterogeneity ($I^2 = 0\%$) in all cases, with a significant effect ($p < 0.00001$). In relation to secondary education, the results reported that the interventions ($k = 7$), with a total of $N = 406$ participants in the experimental group and $N = 414$ in the control group had a significant effect ($p < 0.00001$). Specifically, regarding the components of motivation for learning, the results were as follows: for attention, the effect size was $Z = 3.92$, with homogeneity of $I^2 = 94\%$; for relevance ($Z = 2.70$; $I^2 = 89\%$); for confidence ($Z = 3.83$; $I^2 = 83\%$); and for satisfaction ($Z = 4.80$; $I^2 = 87\%$). In this regard, the high heterogeneity in the analyzed variables indicates that the included studies show significant differences in their results. This suggests that there are variations concerning the set of studies considered for these variables.

Table 3. Meta-analysis on motivation in primary and secondary education.

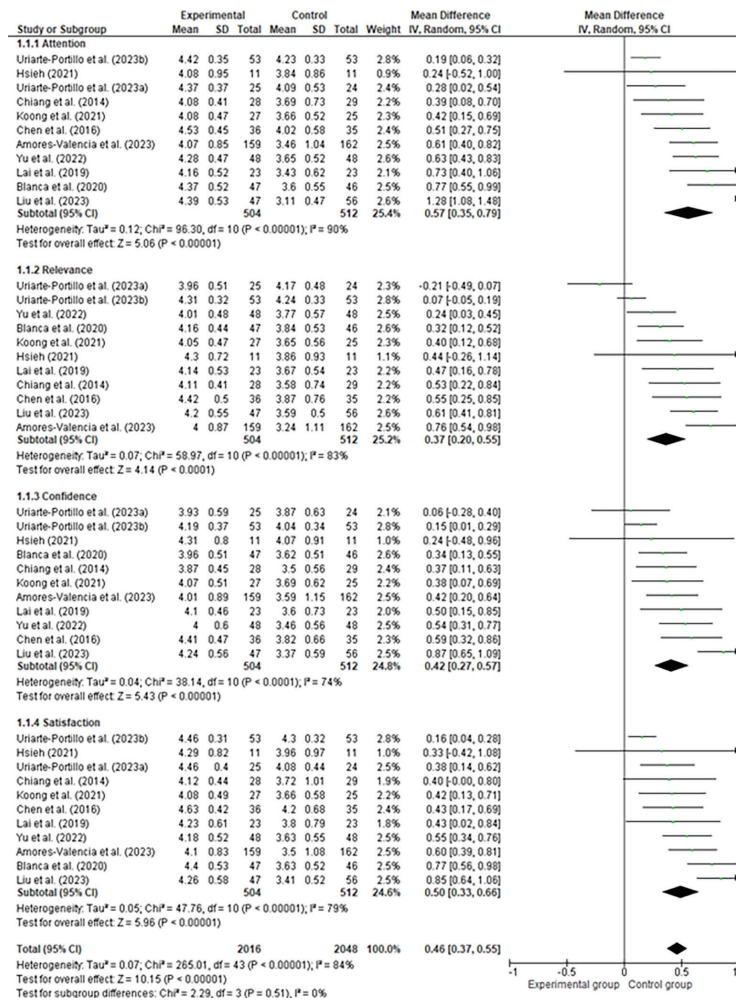
Results	Motivation component	k	SMD	95% confidence interval		Significance (p)	Heterogeneity	
				Lower limit	Upper limit		Z	I ² (%)
Primary Education	Attention	4	0.52	0.36	0.68	<0.00001	6.30	0%
	Relevance	4	0.51	0.34	0.68	<0.00001	5.87	0%
	Confidence	4	0.53	0.33	0.74	<0.00001	5.10	0%
	Satisfaction	4	0.42	0.23	0.61	<0.00001	4.35	0%
Secondary Education	Attention	7	0.60	0.30	0.90	<0.00001	3.92	94%
	Relevance	7	0.31	0.09	0.54	<0.00001	2.70	89%
	Confidence	7	0.40	0.19	0.60	<0.00001	3.83	83%
	Satisfaction	7	0.53	0.31	0.75	<0.00001	4.80	87%

Below is the forest plot of the effect size of the set of interventions carried out in Primary and Secondary Education regarding the influence of AR use on the different components of motivation for learning (Figure 4). In this regard, the meta-analytic results reported the following findings concerning the four components of motivation: for attention, a significant effect was observed across all interventions ($Z = 5.06$; $p < 0.00001$), although heterogeneity was high at $I^2 = 90\%$; for relevance ($Z = 4.14$; $p < 0.00001$) with heterogeneity at $I^2 = 83\%$; for confidence ($Z = 5.43$; $p < 0.00001$) with heterogeneity at $I^2 = 74\%$; and for satisfaction ($Z = 5.96$; $p < 0.00001$) with heterogeneity at $I^2 = 79\%$. However, regarding the overall subgroups, a favorable effect was found ($Z = 10.15$; $p < 0.00001$; $I^2 = 0\%$), indicating that statistical data showed no differences between subgroups ($\text{Chi}^2 = 2.29$; $\text{df} = 3$; $p = .051$; $I^2 = 0\%$).

3.4. Risk of bias of the included studies

Once the studies for the meta-analysis were selected, the reliability of the results was assessed by evaluating the risk of bias using the *Cochrane risk of bias* assessment tool. The *funnel plot* (a graph that checks for publication bias) allows us to observe the results of the risk of bias in the studied psychological parameters (Figure 5). The inspection of the distribution of points in the figure illustrates how each component of motivation for learning

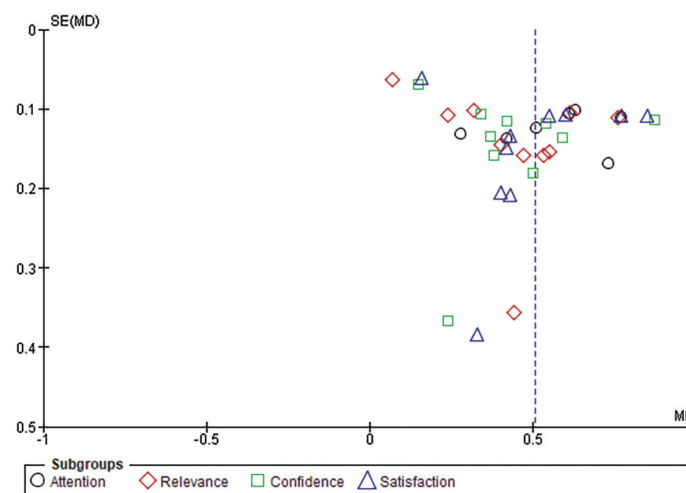
Figure 4. Forest plot of the effect size of the set of interventions.



Note. τ^2 = estimation of the variance of effect sizes; χ^2 = existence of heterogeneity; df = overall indicator of effect size on the results of a meta-analysis; p = statistically significant heterogeneity; green dots = effect size of each study; black diamond for each variable = effect size of the set of studies; final black diamond = subgroup effect size; all studies used the IMMS instrument (Keller, 2010).

(attention, relevance, confidence, and satisfaction) is represented. Thus, it was found that the study conducted by Hsieh (2021) presented the highest risk of bias in each of the evaluated domains.

Figure 5. Overall risk of bias.



4. Discussion

The results obtained have allowed us to address the objective outlined in this research. The review of various studies suggests that the application of AR is a trend to consider in the current educational landscape, particularly at the primary and Secondary Education stages. In fact, this is a topic whose experimentation in classrooms is on the rise, as demonstrated by the diachronic production of the examined articles, most of which were published in 2023. The use of AR is recommended as an alternative in learning activities to increase students' motivation in Primary Education schools (Lai et al., 2019) and in Secondary Education institutions (Liu et al., 2023; Uriarte-Portillo, Zatarain-Cabada, et al., 2023). This means that when applied appropriately, this technology has a positive impact and supports the quality of teaching (Aygün & Çelik, 2024), thereby optimizing learning (Shakirova et al., 2024).

In response to the first question posed, the meta-analysis report indicates that students who engaged in activities using AR have increased their motivation to learn new content compared to those who did not, thus supporting the first hypothesis. Regarding the second research question, the results from the set of interventions suggest that the duration of the intervention does not influence the outcomes. In this regard, the study conducted by Uriarte-Portillo, Blanca, et al. (2023) carries more weight than the other studies. Specifically, its duration was two sessions of sixty minutes, whereas the study conducted by Amores-Valencia et al. (2023) consisted of eleven sessions of sixty minutes and did not present the most significant weight; therefore, the second hypothesis is rejected. On the other hand, in response to the third question proposed, the heterogeneity of the set of interventions has been low, thus affirming the third hypothesis. This suggests that the use of AR in Primary or Secondary Education has a favorable effect on students' motivation for learning.

Regarding the risk of bias, the study by Hsieh (2021) presents the highest risk of bias. In this context, one of the most significant findings was that the study conducted by Hsieh (2021) presented the highest risk of bias in each of the evaluated domains. This finding emphasizes the importance of thoroughly evaluating each study before including it in the meta-analysis, as a study with a high risk of bias can significantly alter the overall results, especially if it occupies a prominent position within the set of studies. Hsieh's study (2021) presents inconsistencies or deficiencies in its design, participant selection (Soriano-Sánchez et al., 2020), or data analysis, which could have unduly influenced the final results. This could justify paying special attention when interpreting the effects of motivation for learning in the different studied domains.

Our results show that the use of AR in Primary and Secondary Education enhances students' motivation towards learning. Furthermore, as reported by Ciloglu and Ustun (2023) and Cheng et al. (2017), its application is suggested to promote socialization, attention, comprehension, self-efficacy, learning, and language development. This indicates a significant improvement in the teaching and learning process when employing more creative and innovative methodologies (Lin et al., 2021; Rueda et al., 2023).

Based on a review of studies, it is considered that the relevance of using AR in the educational field lies in the possibilities it offers to provide real-time digital information, enrich content, and make learning more interactive and participatory (Sáez-López et al., 2019). In fact, in Primary Education, it fosters a greater attitude towards learning and improves comprehension of various content (Phon et al., 2019). The same is true in Secondary Education, as it has been observed that the use of AR facilitates the achievement of curricular objectives by improving outcomes (Fidan & Tuncel, 2019).

However, despite the results obtained, this study is not without limitations. The main limitation may lie in the databases used for the document search, as Web of Science and Scopus were employed. Therefore, studies published in other electronic resources may have been inadvertently omitted. Another limitation is the risk of bias present in some domains of the analyzed variables regarding the Secondary Education stage.

This research highlights the potential of AR to enhance motivation in the learning of Primary and Secondary Education students. AR enables the personalization of teaching by adapting content to each student's needs, providing a practical framework for teachers to integrate this technology into their pedagogical methods, and making learning more interactive and engaging. Educational institutions can utilize these findings to train teachers in the effective use of AR, thereby creating activities that foster active and participatory learning. AR facilitates the understanding of complex concepts and fosters students' intrinsic motivation, thereby improving academic outcomes. Additionally, its implementation supports educational inclusion by addressing different learning styles and individual needs. By integrating AR into classrooms, institutions can promote a culture of technological innovation and prepare students for the challenges of the 21st century, developing essential digital skills. In summary, this research offers a practical guide for leveraging AR to enhance the educational experience, making it more interactive, inclusive, and aligned with current educational demands.

For future lines of research, it would be interesting for new systematic reviews and meta-analytic studies to analyze the potential impact of AR on motivation for learning in Early Childhood Education or higher education. To this end, it is recommended that future meta-analytic research include studies that have used the same assessment instrument to measure a specific variable, thereby minimizing bias as much as possible. Likewise, an increase in the number of studies regarding the stage of secondary education and the variables analyzed is suggested in order to compare the risk of bias in relation to this study.

Ultimately, this study demonstrates the potential of using AR to foster motivation for learning among Primary and Secondary Education students. Its implementation could create collaborative, active, and personalized learning experiences, while also promoting and enhancing students' cognitive and socio-emotional development.

5. Conclusions

This study highlights the positive impact of AR on students' learning motivation in primary and secondary education. Therefore, its implementation is recommended to personalize teaching and ensure the quality of educational responses. It presents itself as an effective alternative for improving content acquisition and academic performance.

Based on the analyzed studies, it is concluded that with just two implementation sessions, there would be an increase in motivation towards learning and in achieving previously established curricular objectives. Furthermore, its use develops media competencies as well as social, cognitive, and emotional skills among students.

In summary, it is advisable to adopt AR as a standard learning approach in primary and secondary education, given its innovative nature and the multiple benefits it offers due to its interactive nature, immediacy, and ability to motivate students. Additionally, it stands out as a valuable tool for promoting universal learning design.

Authors' contribution

Conceptualization: JGSS, DJV, SSR; Data Curation: JGSS, DJV, SSR; Formal Analysis: JGSS, DJV, SSR; Methodology: JGSS, DJV, SSR; Software: JGSS; Supervision: JGSS, SSR; Validation: JGSS, DJV; Original Draft Writing: JGSS, DJV, SSR; Review and Editing: JGSS.

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