Augmented and Virtual Reality in Computational Thinking: A Systematic Review of Their Individual Impacts, Advantages, Challenges, and Future Directions

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Abstract: Computational thinking (CT) skills are increasingly important in education to prepare students for the challenges of the digital age. Augmented Reality (AR) and Virtual Reality (VR) have been introduced as immersive technologies that have the potential to enhance CT skills through more interactive learning experiences. However, there is still a gap in understanding the effectiveness of these technologies in supporting the development of CT, particularly in different levels of education and disciplines. Although several studies have highlighted the benefits of AR and VR in education, no systematic review integrates these findings to identify advantages, challenges, and opportunities for further implementation. Therefore, this study conducted a systematic review based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines by analyzing 25 empirical studies (AR=17, VR=8) obtained from the Scopus database (2008-2024). The analysis addresses four key research questions: (1) the current state of AR/VR in CT development, (2) their advantages, (3) implementation challenges, and (4) future research directions. The results show that AR is more widespread than VR at various levels of education, with dominance in higher education followed by secondary and primary schools. Computer science is the main field of application of AR and VR, while AR is also widely applied in mathematics to increase interest and problem-solving. A total of 11 studies reported significant impacts of these technologies on CT, with AR being superior in increasing student motivation and engagement, as well as aiding in problem-solving and debugging. In contrast, VR provides a more immersive learning experience by strengthening concept understanding, especially in programming and recursion. However, several obstacles in the application of AR and VR, such as hardware limitations, costs, and user skills, affect the effectiveness of these technologies in the learning environment. This study also identified potential future research, including the exploration of VR in primary and kindergarten education, the application of VR in non-computer science fields, and the efficient use of these technologies in supporting the CT process. This study provides more precise insights into the optimal ways of utilizing AR and VR in developing CT skills. It is a reference for educators, policymakers, and researchers in supporting CT learning.

Keywords: Augmented reality, Virtual reality, Computational thinking, Education, Systematic review, PRISMA

1. Introduction

In the rapidly evolving digital era, AR and VR have become two significant technological innovations with great potential to revolutionize various sectors, including education. AR, defined as physical reality enhanced with virtual elements, integrates digital information with the physical world, allowing direct interaction between users and virtual objects in real space without requiring them to focus solely on device screens (Sakr and Abdullah, 2024). By adding digital data in real-time, AR creates engaging, interactive experiences in areas such as education, healthcare, and entertainment while remaining accessible through devices like smartphones or tablets (Dargan *et al.*, 2023; Samala *et al.*, 2023). Conversely, VR is an advanced technology that creates a fully immersive and interactive artificial three-dimensional environment where users can navigate and interact in real-time through sensory channels (Jongbloed, Chaker and Lavoué, 2024). Using specialized headsets or glasses, VR enables students to experience and explore various concepts in realistic simulations separated from the real world (Burdea and Coiffet, 2024). While AR is more accessible due to mobile device compatibility (Fan and Liu, 2011; Begum *et al.*, 2023), VR requires dedicated headsets, limiting its adoption in resource-constrained settings. For instance, the AR market is projected to grow at 30.9% CAGR (Sheena *et al.*, 2023), reflecting broader

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applicability, whereas VR's immersive nature suits specialized training (e.g., programming recursion) but faces higher costs (AlGerafi *et al.*, 2023; Chiliquinga, Arguello and Mayorga, 2025). Despite their different approaches, these two technologies can provide learning experiences that conventional teaching methods cannot deliver (Sakr and Abdullah, 2024). Empirical studies show that integrating AR and VR in education increases student engagement and facilitates a deep understanding of subject matter, especially in science and technology learning (Alzahrani, 2020; Cromley, Chen and Lawrence, 2023).

Along with these technological developments, CT has been identified as one of the essential skills of the 21st century. CT, defined as a cognitive process based on computer science principles, encompasses problem-solving, system design, and abstract thinking (Wing, 2008; Tsai *et al.*, 2022). It includes key components like abstraction, decomposition, generalization, and algorithm design, as well as qualities like confidence and perseverance in addressing challenges (Selby, 2015; Chen *et al.*, 2023). CT serves as an essential foundation across various disciplines, encouraging critical and creative thinking to solve complex problems (Kong, 2022). In the context of education, AR and VR have been shown to support CT development by providing interactive learning environments that allow students to apply computational thinking skills in both real and simulated scenarios (Abdul Hanid *et al.*, 2022a; Huang, Tarng and Ou, 2023). For instance, AR supports abstraction and generalization through interaction with digital objects that represent real-world concepts (Lin *et al.*, 2021; Koumpouros, 2024). Meanwhile, VR offers immersive learning settings that enable students to explore, visualize, and manipulate abstract concepts like algorithms and data structures in scenarios close to reality (Agbo, Oyelere, *et al.*, 2023; Oyelere, Agbo and Oyelere, 2023). Together, AR, VR, and CT provide transformative opportunities to enhance learning experiences and equip students with essential skills for the digital age.

Various studies have explored the application of AR and VR technologies in education, particularly in the context of developing CT skills. For instance, Angraini et al. (2024) investigated the effectiveness of AR in enhancing middle school students' CT skills through a quasi-experimental approach. The study revealed that using AR in mathematics learning significantly improved CT skills compared to conventional methods. Similarly, Theodoropoulos and Lepouras (2021) conducted a systematic review of the use of AR in programming education, finding that while AR positively impacts CT learning, further analysis is needed to understand its characteristics, advantages, and limitations. Acevedo-Borrega et al. (2022) provided a broad review of CT and educational technology, highlighting the need for a more comprehensive understanding of the roles of curriculum and teachers in CT development. However, their review offered limited insights into how AR and VR could be integrated into CT learning strategies. Additionally, Sukirman et al. (2022) discussed game-based CT learning strategies using VR. Although they proposed a conceptual framework linking game elements, VR features, and CT skills, their study was limited in scope, reviewing only 15 studies. While several studies have attempted to address the integration of AR and VR in education, most have focused only on general benefits, such as increased student engagement and improved learning outcomes for specific subjects. In-depth analyses of the impacts, challenges, and future directions for using AR and VR in CT development across various educational contexts remain rare. This indicates a critical gap in the literature.

As illustrated in Figure 2, from 2008 to the present, only 100 publications on Scopus have discussed AR in the context of CT, and 113 publications have examined VR and CT. These figures suggest that research in this domain is still in its early stages. In contrast, other educational technologies have been extensively studied in relation to CT. For example, X. Wang et al. (2023) reviewed game-based learning (GBL) for CT development, highlighting its potential while identifying shortcomings in addressing CT elements such as abstraction and triggers. Varghese and Renumol (2024) explored video games as CT assessment tools but noted a lack of empirical evidence supporting their effectiveness. Belmar (2022) presented a global review of CT and programming education, emphasizing significant gaps between developed and developing regions but without a focus on AR or VR. Even in studies specifically addressing AR and VR, such as Theodoropoulos and Lepouras (2021), analyses remain limited to general insights without a detailed evaluation of these technologies' roles in CT. It underscores the novelty of the present study, which represents the first systematic review comprehensively evaluating AR and VR contributions to CT development across educational levels and subjects.

Therefore, this study aims to bridge these gaps by addressing the following research questions:

- RQ1: What is the current state of research on AR and VR in CT development, considering educational levels, target subjects, and practical outcomes?
- RQ2: What are the advantages of using AR and VR for CT development?
- RQ3: What challenges exist in implementing AR and VR to enhance CT?
- RQ4: What are the future research directions to optimize AR and VR for CT development?

By answering these questions, this review provides a comprehensive foundation for educators and policymakers.

2. Methods

A systematic review is a rigorous and comprehensive approach to summarizing and evaluating the existing research literature on a particular topic or research question that involves systematically searching, selecting, appraising, and synthesizing multiple studies to provide an unbiased and reliable overview of the available evidence (Aromataris and Pearson, 2014). This study adopted a commonly used three-step methodology in systematic reviews (Yadegaridehkordi *et al.*, 2019; Wang and Chan, 2024). The first step is the implementation of an appropriate keyword search strategy. The second step involves the selection and quality assessment of the literature found. The final step is coding to answer the research questions. Each step is described in detail below to provide a clear picture of the process used in this study.

2.1 Search Strategy

The first step in this research was to design and implement an effective search strategy to find relevant studies. Researchers used the Scopus database, which is recognized as one of the most comprehensive sources of scientific literature (Festiyed, Tanjung and Fadillah, 2024; Maral, 2024). Scopus was chosen because it covers a wide range of disciplines and source types, including peer-reviewed journals, conferences, and other academic publications. It ensures that the scope of data retrieved is broad and of high quality. Scopus also has a rigorous selection process for the sources included, so the data obtained is generally considered highly reliable. In addition, Scopus includes most journals that are also indexed in Web of Science, Medline, Google Scholar, and Embase, making it a very comprehensive source for this study (AlRyalat, Malkawi and Momani, 2019; Zyoud *et al.*, 2023). While Scopus covers most journals indexed in Web of Science and PubMed (AlRyalat, Malkawi and Momani, 2019), future reviews could include multiple databases to mitigate selection bias.

Searches were conducted using specific keywords to identify studies that address AR and VR in the context of computational thinking. The keywords used for the AR search were ("augmented reality" OR "AR"), and for VR, were ("virtual reality" OR "VR"). These keywords were combined with the term "computational thinking" to ensure that all studies relevant to the research topic were identified. In addition, to limit the search to the educational context, additional phrases from the systematic literature review by Z. Wang & Chan (2024) were used, namely educat* OR student* OR learn* OR teach* OR class*. These phrases helped ensure that the studies found were relevant to the use of AR and VR in education for the development of computational thinking.

It is important to note that the search was conducted separately for AR and VR. It means that each topic was analyzed independently to identify relevant literature. The search was conducted on article titles, abstracts, and keywords all at once (TITLE-ABS-KEY), without any specific time limit, to ensure that all relevant studies, both new and old, were captured in the search. All data for this study were downloaded on July 21, 2024, to avoid potential bias due to the continuous updating of the Scopus database.

2.2 Selection and Quality Assessment

After implementing the search strategy, the next step was to select and assess the quality of the literature found. The data exported from Scopus was saved in "csv" format and analyzed using Microsoft Excel. This export file contains important information such as title, abstract, link, DOI, and others. From our database search, we identified 213 relevant records, consisting of 100 records for AR and 113 records for VR (see Figure 1). All records were from one database (Scopus), and no duplicate records needed to be removed. We manually screened all records carefully using meta-data (title and abstract) to assess whether they met the inclusion and exclusion criteria. Exclusion criteria included articles for which full text was not available, non-empirical studies, topics not related to the use of AR and VR in the development of computational thinking, non-educational purposes, and articles not written in English. In contrast, the inclusion criteria included articles for which full text was available, empirical studies, topics related to the use of AR and VR in the development of computational thinking, educational purposes, and written in English. It is important to note that these criteria were not applied simultaneously to AR and VR but rather applied separately to each topic. In other words, studies relating to AR and VR were analyzed individually, with the same exclusion and inclusion criteria, but applied separately to ensure a more in-depth understanding of each technology's impact on computational thinking.

After the initial screening, 179 records were removed from further analysis, consisting of 79 for AR and 100 for VR. These deletions were mainly due to the irrelevance of the topic, not an empirical study, and not for educational purposes. Of the remaining records, we excluded 2 records for VR due to lack of relevance to the research topic. We then analyzed the full text of the remaining 32 publications, consisting of 21 for AR and 11 for VR. Of these publications, 25 studies (AR = 17; VR = 8) were judged eligible for this review. Studies were mostly excluded because the full text was unavailable and not written in English (see Figure 1). The studies included in this research are listed in the Table 1.

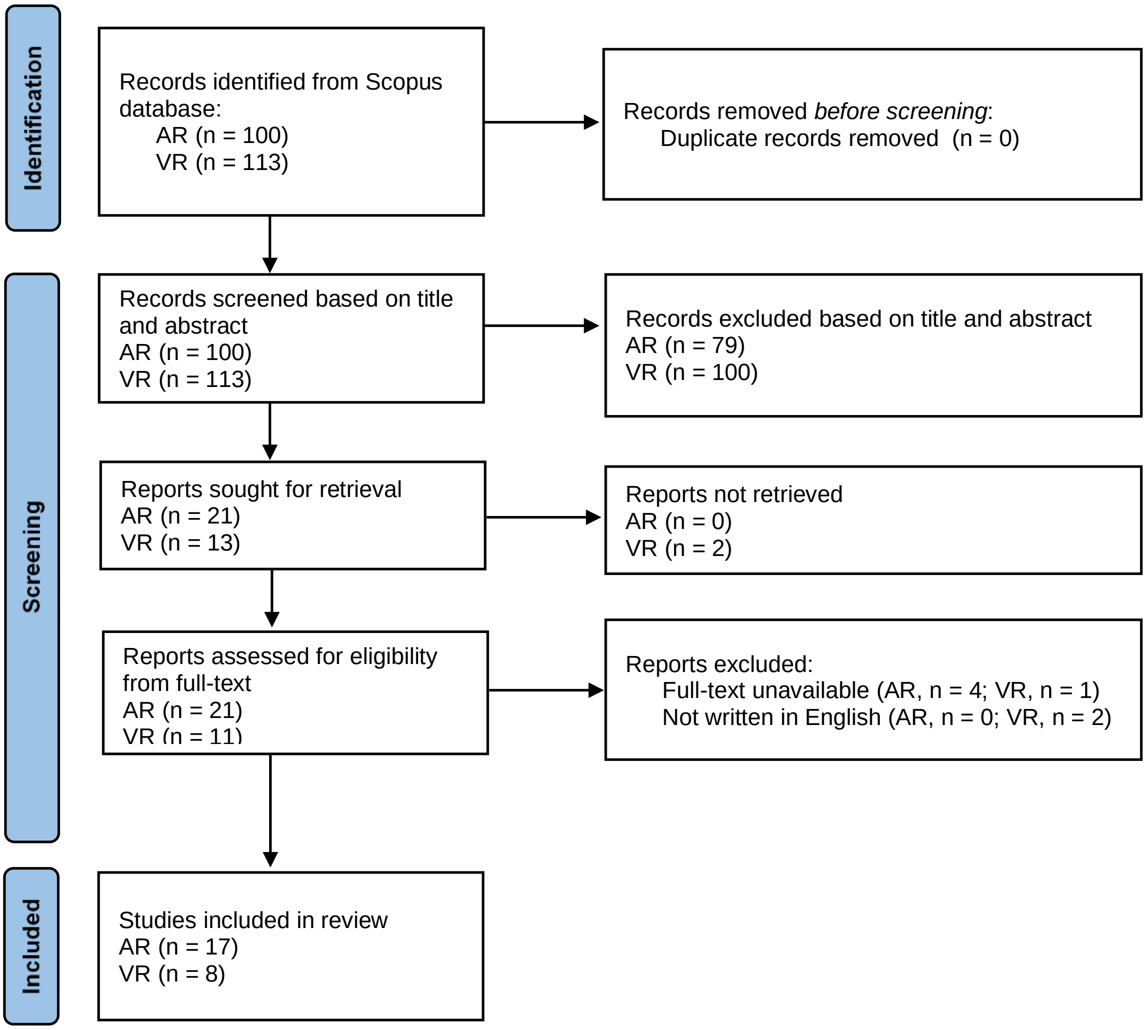

Figure 1: Article selection process based on PRISMA

Table 1: Studies included in review

Author(s)	Article topic	Participants' educational levels	Objective subjects	Practical impacts
Angraini et al. (2023)	AR	Secondary school	Mathematics	Major effect
Angraini et al. (2024)	AR	Secondary school	Mathematics	Major effect
Işik Arslanoğlu et al. (2024)	AR	Kindergarten	Computer science	Major effect
Chung & Hsiao (2020)	AR	Higher education	Computer science	Major effect
Esteves et al. (2019)	AR	Elementary school	General objective	Effective
Gardeli & Vosinakis (2019)	AR	Elementary school	General objective	Effective
Gardeli & Vosinakis (2020)	AR	Elementary school	Computer science	Effective
Abdul Hanid et al. (2022a)	AR	Secondary school	Mathematics	Major effect

Author(s)	Article topic	Participants' educational levels	Objective subjects	Practical impacts
Abdul Hanid et al. (2022b)	AR	General education	Mathematics	Effective
Hidayat et al. (2024)	AR	Higher education	Electronics engineering education	Major effect
Huang et al. (2023)	AR	Elementary school	Computer science	Major effect
Lee & Hsu (2023)	AR	General education	General objective	Effective
P.-H. Lin & Chen (2020)	AR	Higher education	General objective	Major effect
Y.-S. Lin et al. (2021)	AR	General education	Computer science	No effect
Lunding et al. (2022)	AR	Elementary school	General objective	Effective
Saraiva et al. (2021)	AR	General education	General objective	Effective
Ou Yang et al. (2023)	AR	Higher education	Computer science	Minor effect
Agbo et al. (2021)	VR	General education	General objective	Effective
Agbo, Oyelere, et al. (2023)	VR	Higher education	Computer science	Major effect
Agbo, Olaleye, et al. (2023)	VR	Higher education	Computer science	Major effect
Chen et al. (2020)	VR	General education	Computer science	Effective
Coenraad & Weintrop (2018)	VR	Secondary school	General objective	Effective
Gerini et al. (2023)	VR	Secondary school	Computer science	Effective
Sims et al. (2021)	VR	Higher education	Computer science	Minor effect
Lai et al. (2021)	VR	Higher education	Information engineering	Major effect

Note: We used "general education" and "general objective" because the study did not clearly specify the participants' educational levels or the target subjects. Therefore, we decided to use the term "general" for clarity.

2.3 Coding Scheme

Once selection and quality assessment were applied, the next step was data extraction and coding. Coding was conducted based on procedures developed from a previous systematic review with the aim of answering the research questions posed (Wang and Chan, 2024). Coding involved identifying and recording important data from each selected article, including education level, target subjects, practical effects, advantages, and challenges of using AR and VR in the development of computational thinking. Each selected article was reviewed in detail by the authors, and the necessary data was recorded using Microsoft Excel. Each selected article was coded independently by two authors to ensure consistency and accuracy in coding. After the initial coding was completed, the coding results were compared to identify similarities and differences. In case of disagreement between the two authors in coding, the differences were discussed in a group discussion involving all authors. This approach allows for more comprehensive discussions and more collective decision-making (Richards, Hemphill and Flory, 2022). Suppose after discussion there are still significant differences. In that case, a final decision will be made based on a majority vote, or, if required, a senior researcher will be asked to provide a final opinion. This systematic coding process ensures that all important aspects of relevant studies are carefully identified and analyzed so that the results of this research can make a significant contribution to understanding the role of AR and VR in the context of computational thinking.

3. Results

3.1 Analysis of Publication Descriptions Taken From Publication Trends

The publication trend on AR and VR in the context of computational thinking shows a significant increase in recent years (see purple line in Figure 2). Publications on AR have increased since 2016, with a peak in 2023 of 25 publications. Although the 2024 data only covers up to July 21, there are already 10 publications identified, indicating continued interest. VR has also seen an annual increase, with a peak of 33 publications in 2023 and 7 publications in 2024 through July 21. Some publications were selected for systematic review according to specific criteria (see orange lines in Figure 2). AR studies that met the criteria ranged from 2019 to 2024, mostly from 2023, reflecting the peak of the literature. For VR, relevant studies were from 2018 to 2023, with a predominance of recent literature from 2023, which makes an important contribution to the understanding of the use of VR in the development of computational thinking.

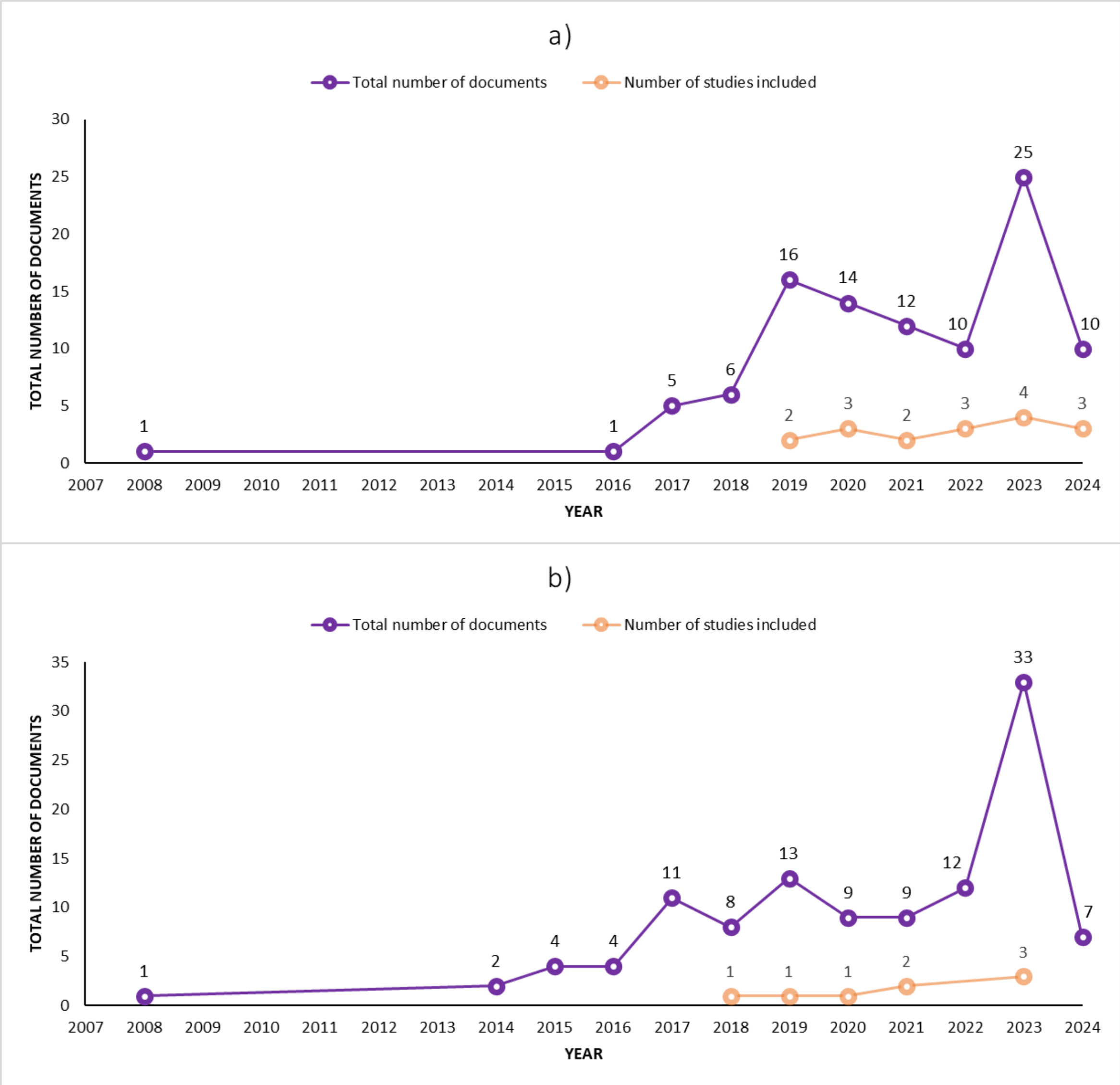

Figure 2: Total number of documents and number of studies included: a). Documents for AR in the context of computational thinking; b). Documents for VR in the context of computational thinking

3.2 Participants' Educational Levels

Table 2 shows that most studies (32%) focused on AR and VR at the college level, with VR (50%) more prevalent than AR (23.53%). Higher education dominates their application, leveraging students' advanced computational thinking (CT) development skills. In secondary schools (20%), AR appeared in 3 studies (17.65%) and VR in 2 (25%), enhancing engagement and meaningful learning. AR was more common in primary schools (5 studies, 29.41%), while VR was absent, indicating AR's potential for early technology exposure. One study (5.88%) explored AR in kindergarten for basic CT skills, but VR was not used, likely due to student limitations. Additionally, 24% of studies did not specify an educational level but examined AR (4 studies) and VR (2 studies) in general CT development. AR (68%) was more widely used than VR (32%), likely due to its easier integration across different education levels.

Table 2: Educational levels of AR and VR study participants

Educational levels	Number of ARs	% AR	Number of VRs	% VR	Total	Total (%)
Kindergarten	1	5.88	0	0.00	1	4.00
Elementary school	5	29.41	0	0.00	5	20.00
Secondary school	3	17.65	2	25.00	5	20.00
Higher education	4	23.53	4	50.00	8	32.00
General education	4	23.53	2	25.00	6	24.00
Total	17	100.00	8	100.00	25	100.00

3.3 Objective Subjects

Figure 3 shows that AR and VR are primarily used in computer science, with 11 AR and 5 VR studies enhancing programming and CT skills through practical approaches like coding (Chen, Lai and Lin, 2020) and robotics (Ou Yang, Lai and Wang, 2023). VR is also integrated into game-based learning, fostering problem-solving through algorithms, decomposition, and pattern recognition (Agbo, Olaleye, *et al.*, 2023; Lee and Hsu, 2023), while interactive VR games boost engagement and cognitive abilities (Agbo *et al.*, 2021; Agbo, Oyelere, *et al.*, 2023). AR has also been applied in mathematics (4 studies), using animated visualizations to enhance problem-solving interest, while VR was not explored in this field. In electronic and information engineering, one AR and one VR study demonstrated benefits for intellectual development. Additionally, eight studies investigated AR and VR in general education contexts, highlighting their versatility, though VR use in computer science still needs further exploration.

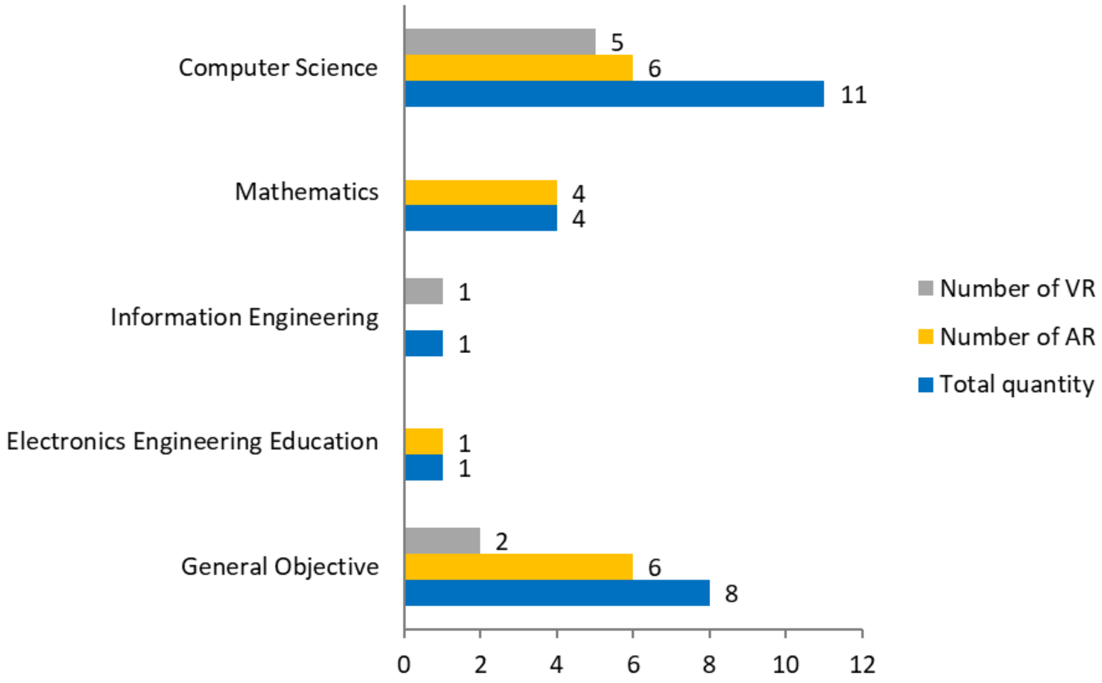

Figure 3: Target study subjects

3.4 Practical Impact

Table 3 summarizes the practical impact of using AR and VR on CT. Of the 25 studies analyzed, 11 studies reported a significant impact or major effect on students' CT, where AR recorded a major effect ratio of 0.47 and VR of 0.38. This significant effect is mainly related to AR and VR's ability to provide an interactive learning environment that supports problem-solving and higher student engagement (Gardeli and Vosinakis, 2020). On the other hand, 11 studies reported these technologies as effective, i.e., having a positive impact on improving students' CT, although without testing the level of significance. The use of AR in the effective category showed a ratio of 0.41, while VR reached a ratio of 0.50. Studies in the effective category show that AR and VR are capable of enriching students' learning experience but focus more on the process of using the technology rather than on its measurable outcomes or impact. In addition, some studies noted limitations to the impact of these technologies. Two studies showed minor impacts, one for AR (Ou Yang, Lai and Wang, 2023) and one for VR (Sims *et al.*, 2021), and there was one study that found that AR did not affect students' CT (Lin *et al.*, 2021). Barriers such as time constraints, technical difficulties, and the need for additional support in technology-based learning also affect the effectiveness of AR and VR (Gardeli and Vosinakis, 2020; Işik Arslanoğlu, Kert and Tonbuloğlu, 2024).

Table 3: The practical impact of AR and VR

Practical impacts	Quantity of AR	Quantity of VR	Total	Impact to Number of Technology Ratio	
				AR Ratio	VR Ratio
Major effect	8	3	11	0.47	0.38
Moderate effect	0	0	0	0.00	0.00
Effective	7	4	11	0.41	0.50
Minor effect	1	1	2	0.06	0.13
No effect	1	0	1	0.06	0.00
Sum	17	8	25	1.00	1.00

3.5 Advantages of Using AR and VR in CT Development

AR and VR technologies have a significant role in the development of CT skills in students (refer to Table 4). AR can increase learning motivation, engagement (Abdul Hanid *et al.*, 2022a; Angraini, Yolanda and Muhammad, 2023; Angraini *et al.*, 2024; Işik Arslanoğlu, Kert and Tonbuloğlu, 2024), and facilitate problem-solving (Lin and Chen, 2020; Saraiva *et al.*, 2021; Abdul Hanid *et al.*, 2022a) and debugging in learning (Chung and Hsiao, 2020; Abdul Hanid *et al.*, 2022b; Huang, Tarng and Ou, 2023). Moreover, AR is particularly useful for children, including those with special conditions such as ASD (Autism Spectrum Disorder) (Lee and Hsu, 2023), in developing computational thinking through an intuitive approach (Esteves, Santana and Lyra, 2019; Gardeli and Vosinakis, 2020). On the other hand, VR helps students engage more intensely through immersive virtual environments deepen recursion understanding (Coenraad and Weintrop, 2018; Lai *et al.*, 2019; Agbo *et al.*, 2021; Agbo, Olaleye, *et al.*, 2023; Agbo, Oyelere, *et al.*, 2023; Gerini *et al.*, 2023), as well as facilitate reflective thought processes that support conceptual understanding in CT (Agbo, Oyelere, *et al.*, 2023).

Table 4: The main advantages encountered in the use of AR and VR technologies for CT development in students

Technology	Main advantages	Explanation	Reference
AR	Facilitates feedback and engagement	AR supports immediate feedback, engaging interactions, and in-depth learning content that reinforces understanding of the material	Abdul Hanid et al. (2022a); Angraini et al. (2023), (2024); Işik Arslanoğlu et al. (2024)
	Supports problem-solving	AR helps students think critically in problem-solving and motivates them to improve academic performance	Abdul Hanid et al. (2022a); P.-H. Lin & Chen (2020); Saraiva et al. (2021)
	Strengthens algorithmic and debugging skills	AR effectively improves algorithmic thinking skills and helps in debugging tasks by reducing errors in code design	Abdul Hanid et al. (2022b); Chung & Hsiao (2020); Huang et al. (2023)
	Improving special children's CT skills	With games and social strategies, AR can help ASD children learn CT more intuitively and engagingly	Lee & Hsu (2023)
	Developing basic CT skills at the elementary level	AR encourages students to create a game design map, training them to plan and calculate steps	Esteves et al. (2019); Gardeli & Vosinakis (2020)
VR	Increases engagement and immersion	VR provides access to realistic virtual environments and supports students' full engagement in learning	Agbo et al. (2021); Coenraad & Weintrop (2018); Gerini et al. (2023)
	Facilitating CT development through complex learning	VR supports complex learning processes such as algorithmic thinking, problem decomposition,	Agbo, Oyelere, et al. (2023); Lai et al. (2019)

Technology	Main advantages	Explanation	Reference
		and pattern recognition, which are important in CT development	
	Improving understanding of recursion	The high interaction and engagement of students with VR can improve their understanding of the concept of recursion	Agbo, Olaleye, et al. (2023)
	Supports reflection and understanding of CT concepts	VR helps the reflective thinking process that promotes students' deep understanding of CT concepts	Agbo, Oyelere, et al. (2023)

3.6 Challenges of Using AR and VR in CT Development

The use of AR and VR technologies in the development of CT faces various challenges, especially in the aspects of limited device technology and high development costs (refer to Table 5). The use of AR is still limited by hardware quality (Esteves, Santana and Lyra, 2019; Lunding *et al.*, 2022; Angraini *et al.*, 2024), interaction features (Chung and Hsiao, 2020), time and cost (Esteves, Santana and Lyra, 2019; Gardeli and Vosinakis, 2020), and student dependence on teacher guidance (Gardeli and Vosinakis, 2020; Angraini *et al.*, 2024). In addition, different levels of interest based on gender also affect the effectiveness of AR use in the classroom (Angraini, Yolanda and Muhammad, 2023). Meanwhile, VR requires high-quality devices (Sims *et al.*, 2021; Gerini *et al.*, 2023), adequate user experience (Agbo, Oyelere, *et al.*, 2023), adequate cognition (Huang, Tarng and Ou, 2023), and adaptation time due to potential physical discomfort (Coenraad and Weintrop, 2018). Cost and educator skill factors also limit the utilization of VR in education (Coenraad and Weintrop, 2018; Chen, Lai and Lin, 2020), although its potential for CT development is significant.

Table 5: The main challenges faced in the use of AR and VR technologies for CT development in students

Technology	Main challenges	Explanation	Reference
AR	Device technology limitations	Sub-optimal hardware quality prevents AR from functioning optimally; some devices do not support the expected performance	Angraini et al. (2024); Esteves et al. (2019; Lunding et al. (2022)
	Dependence on graphic quality and interaction	AR does not yet support tracking eye gaze and hand movements, limiting interaction with virtual content	Chung & Hsiao (2020)
	Requires guidance in its use	Students have difficulty understanding difficult material and need teacher support for discussion	Angraini et al. (2024); Gardeli & Vosinakis (2020)
	Development is costly and time-consuming	AR application development is time-consuming and costly and requires the development of scenarios according to students' learning needs	Esteves et al. (2019); Gardeli & Vosinakis (2020)
	Unevenness of interest by gender	Male students' interest in using AR is higher than females, which may be influenced by the perception of AR as a "game."	Angraini et al. (2023)
VR	Dependence on user experience	Many students are still new to using VR so it takes time for adaptation.	Agbo, Oyelere, et al. (2023)
	Cognitive difficulties in understanding the material	Complex learning materials can cause a high cognitive load for students	Huang et al. (2023)
	Technological limitations of VR devices	The quality of graphics, navigation, and instruction in VR still needs improvement to meet learning needs	Gerini et al. (2023); Sims et al. (2021)
	High cost and limited educator skills	The utilization of VR in CT education is still limited due to the cost and inadequate skills of educators.	S.-Y. Chen et al. (2020); Coenraad & Weintrop (2018)
	Physical comfort factor	Head-mounted VR devices can cause discomfort, so it takes time for user adaptation.	Coenraad & Weintrop (2018)

3.7 Future Research of Using AR and VR for CT Development

There is some potential for future research into using AR and VR to support CT development in education. This study can help increase various parties' understanding of the impact of advanced technology in education.

- **Use of VR at elementary school and kindergarten levels**: Table 1 shows that AR technology has been applied at all levels of education. Six studies show that AR has been successfully used to support CT development in students in primary schools and kindergartens, proving that children at this level are quite capable of using high technology. As VR shares similar characteristics with AR, future research could test the potential of VR to develop CT in students at these two levels of education, as well as understand the capabilities and challenges they face.
- **Use of VR in non-computer science disciplines**: Currently, the use of VR for CT development is mostly in computer science-related fields (see Figure 3). Since AR has been applied in various non-computer science disciplines, such as mathematics, future research could examine the use of VR in other fields, such as mathematics, biology, and physics, to broaden the horizon of the application of VR in various disciplines.
- **Efficiency of VR use to support the ct process**: The quality of technology is proven to affect students' CT development. The use of advanced technology can increase comfort and ease of use (Esteves, Santana and Lyra, 2019). Previous study recommendations suggest that future researchers explore the efficiency of VR devices and track constraints on them (Gerini *et al.*, 2023). The results will provide important insights into how much VR efficiency can affect user adoption and reliance on this technology in studying CT in education.
- **Use of AR in various disciplines**: Several studies have examined the application of AR in computer science, mathematics, electronics engineering education, and information engineering. Future studies could examine the benefits of AR in other disciplines, such as physics, biology, and chemistry, to create more engaging and visually real learning experiences (Angraini, Yolanda and Muhammad, 2023; Angraini *et al.*, 2024).
- **Number and environment of participants in AR research**: The number of participants and the research environment or location have the potential to provide new insights into AR's effectiveness. Future studies could increase the number of participants (Gardeli and Vosinakis, 2020; Angraini, Yolanda and Muhammad, 2023; Ou Yang, Lai and Wang, 2023) and test AR implementation in different environments to see the impact of using this technology in various locations (Chung and Hsiao, 2020; Gardeli and Vosinakis, 2020).
- **The effect of CT elements on academic achievement in AR use**: The study of Abdul Hanid et al. (2022a) shows that AR-based learning with CT has a positive impact on student academic achievement but has yet to examine all CT elements. Ou Yang et al. (2023) found that the algorithm design element had a positive impact. However, this may be due to limited time, making students focus on solving questions without using efficient algorithms. Future studies could examine all elements of CT, such as pattern recognition, abstraction, generalization, decomposition, and debugging, and their impact on academic achievement with a longer research duration.

4. Discussions

The findings of this study demonstrate a notable rise in the application of AR and VR technologies for developing CT skills, with a surge in research output in 2023 (RQ1). This trend suggests an increasing recognition of the potential of immersive technologies in education. One major factor driving this rise is the COVID-19 pandemic, which accelerated the adoption of digital and immersive learning tools to address challenges posed by remote learning. Bermejo et al. (2023) highlight how the pandemic catalyzed the integration of AR and VR as educators sought innovative ways to maintain student engagement and facilitate interactive learning in virtual environments. This surge aligns with broader shifts toward digital transformation in education, further emphasizing the relevance of these technologies in a post-pandemic world (Matsieli and Mutula, 2024).

AR and VR have been adopted at various educational levels, with AR more prevalent in primary education due to its accessibility and child-friendly nature. Our findings align with Pellas et al. (2019) and Radu (2012), who noted AR's suitability for younger learners due to its intuitive interface. Conversely, VR is favored in higher education settings, where complex cognitive skills, such as recursion and algorithmic thinking, are required. Bermejo et al. (2023) and Radianti et al. (2020) similarly emphasize VR's role in enhancing engagement and comprehension of abstract concepts in advanced learning environments. The constructivist framework explains how AR/VR's interactive environments align with active learning principles (AlGerafi *et al.*, 2023; Vashisht, 2024; Kononov *et al.*, 2025), reinforcing CT skills like abstraction (see Table 4). AR's dominance in primary education (29.41% of studies, Table 2) correlates with its lower cost and device compatibility (Fan and Liu, 2011; Begum *et al.*, 2023), whereas VR's scarcity (0% in primary schools) reflects infrastructural barriers.

The advantages of AR and VR in CT development (RQ2) extend beyond engagement, significantly enhancing problem-solving, debugging, and algorithmic thinking. Theodoropoulos and Lepouras (2021) highlight AR's impact on programming education, providing immersive visualizations that aid understanding. Similarly, VR supports reflective and deep thinking, as noted by Elmqaddem (2019), enabling students to interact with complex problem spaces in ways traditional methods cannot replicate. This immersive learning experience fosters greater retention and application of CT concepts, as supported by K.-T. Huang et al. (2019) and Reeves et al. (2021), who found VR and AR effective in promoting experiential learning in science disciplines.

However, this study also identifies significant challenges (RQ3), echoed in the broader literature. The high cost of VR devices and the technical expertise required for effective implementation remain barriers to widespread adoption, particularly in underfunded educational systems. Belmar (2022) and Radianti et al. (2020) note similar issues, suggesting that financial constraints and limited access to training for educators hinder the integration of these technologies. Furthermore, gender disparities in AR engagement, where male students exhibit higher interest, mirror findings by Khan and Khan (2019), pointing to the need for more inclusive approaches to technology adoption. Physical discomfort and adaptation challenges with VR technology also pose obstacles, as highlighted by Barteit et al. (2021) and Pellas et al. (2019), necessitating improved device ergonomics and user acclimatization processes.

Future research should address these gaps (RQ4), exploring VR's potential in early education to nurture CT skills from a young age. DeJarnette (2018) and Radu (2012) emphasize the need to adapt immersive technologies for younger learners, leveraging AR's accessibility to introduce foundational CT concepts. Additionally, expanding the application of AR and VR beyond computer science to subjects like biology and math could broaden their educational impact. K.-T. Huang et al. (2019) found AR particularly effective in improving knowledge retention in science education. Exploring interdisciplinary applications could reveal new opportunities for these technologies to enhance learning in diverse contexts.

Nonetheless, there are limitations in this study that need to be recognized. First, this analysis used the Scopus database as the primary source for relevant articles. Although Scopus is one of the most comprehensive academic databases for reviews (Festiyed, Tanjung and Fadillah, 2024; Maral, 2024), relying solely on this data source may exclude important publications found in other databases such as PubMed or Web of Science. This limitation may affect the generalizability of the findings, as insights from these omitted sources could provide a more nuanced understanding of AR and VR applications. In addition, the list of keywords used in this study was based on previous literature, primarily focusing on the educational field (Wang and Chan, 2024). While this method aimed to cover a broad spectrum of relevant terms, some crucial keywords may have been excluded. This limitation could lead to false negative results, potentially overlooking studies significant to the research objectives. Therefore, future reviews should consider diverse keyword strategies and include multiple databases to ensure a more comprehensive analysis.

5. Conclusion

The results of this study indicated significant developments in the use of AR and VR to support CT development. Both technologies have demonstrated substantial benefits in improving computational thinking skills, problem-solving, and student engagement. However, challenges such as device accessibility, educator skill limitations, and differences in student interest underline the need for effective mitigation strategies. In addition to providing insights into the effectiveness of AR and VR, this study underscores the importance of addressing these challenges. Educators should prioritize AR for early CT development due to its accessibility, while VR is better suited for advanced concepts in higher education. Policymakers must address cost barriers through funding initiatives. Future research should focus on adapting these technologies across different educational contexts, evaluating their impact on broader disciplines, and developing more inclusive and cost-effective implementation guidelines. For example, explore VR in kindergarten settings (as AR has shown promise, Işik Arslanoğlu et al., 2024) and interdisciplinary applications (e.g., biology) to broaden CT integration. By doing so, the benefits of AR and VR in CT development can be fully realized across various educational levels and learning environments.

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