



The integration of artificial intelligence, robotics, and computational thinking in education: Overview and trends

Marcelino Sendarrubias-Hipólito ^{1*}

 0009-0004-9727-3466

Miriam Agreda-Montoro ¹

 0000-0002-0940-6504

Javier Rodríguez-Moreno ¹

 0000-0002-5890-3654

Ana María Ortiz-Colón ¹

 0000-0003-0440-6107

¹ Universidad de Jaén, Jaén, SPAIN

* Corresponding author: msh00026@red.ujaen.es

Citation: Sendarrubias-Hipólito, M., Agreda-Montoro, M., Rodríguez-Moreno, J., & Ortiz-Colón, A. M. (2026). The integration of artificial intelligence, robotics, and computational thinking in education: Overview and trends. *Contemporary Educational Technology*, 18(2), Article ep660. <https://doi.org/10.30935/cedtech/18600>

ARTICLE INFO

Received: 27 Jan 2026

Accepted: 29 Apr 2026

ABSTRACT

This systematic review examines the simultaneous integration of artificial intelligence, educational robotics and computational thinking in formal education environments. In a global situation marked by digital transformation, it was found that little research has been carried out into these three key areas taken as a whole. The methodology employed followed the PRISMA guidelines, with searches being conducted in Web of Science, Scopus, and Semantic Scholar for works published between 2018 and 2025. After applying strict inclusion and exclusion criteria, 16 empirical studies were analyzed. The results indicate an exponential increase in recent studies employing active methodologies like project-based learning, the STEAM approach and cooperative learning. The interventions analyzed produced significant improvements in cognitive competencies, motivation and collaboration skills. Three thematic clusters were identified—emerging technologies, education designs, and syllabus strategies. Authors highlighted benefits such as the personalization of learning, the development of 21st century competencies and preparation for entry into the labor market, while also describing challenges associated with teacher training, technological infrastructure and digital equality. This review helps consolidate an emerging field of study, demonstrating the need for more in-depth future research into the joint implementation of such innovations in teaching contexts.

Keywords: artificial intelligence, educational robotics, computational thinking, digital competence, systematic review

INTRODUCTION

The fourth industrial revolution (Industry 4.0) has made technology the main driving force behind social and economic transformation (Trijueque & Marañón, 2022). In this context of rapidly progressing digitalization, where automation, artificial intelligence (AI) and robotics are redefining employment markets, it is indispensable for workers to develop new technological and cognitive competencies. Here, education poses a major challenge: that of preparing people to be not only users of technology but also individuals capable of understanding, creating and critically evaluating complex technological systems. But although studies into educational robotics, computational thinking and AI feature prominently in scientific literature as separate areas of study, there is a noticeable lack of research into the simultaneous integration of all three elements in the educational context.

The main challenge facing this new form of literacy is to transform students' and teachers' concepts of what technology is and how it works. To do so, new learning spaces must be created in which students can be enabled to solve problems using such tools (Carrillo et al., 2024). Within this basic framework for the development of 21st century competencies, three main areas can be identified: robotics, computational thinking and AI. These three pillars constitute the object of our analysis and their application and impact in the educational context will be examined in this review.

Taken individually, all three of these technologies have demonstrated their usefulness in teaching-learning processes. Educational robotics has made it possible to develop experience-based learning and boost cross-sectional competencies like creativity and teamwork (González-Fernández et al., 2021). It also activates motivation through scientific curiosity and experimentation (Barrera-Pacheco, 2023) and is able to generate transformative learning environments (Sánchez et al., 2020). Furthermore, it is considered a valuable resource for inclusion insofar that it facilitates student participation in an equal opportunities environment (Jiménez, 2022). Alongside robotics, Wing (2006) sees computational thinking as a procedure that articulates the use of computing-related concepts to efficiently solve problems and explain systems engineering and human behavior mechanisms. It also provides tools with which to solve problems that lie beyond the scope of academic syllabuses (Zapata-Ros, 2015) and its cultivation aids logic and mathematical reasoning (Gamito et al., 2022; Vera, 2019). Indeed, although originally associated exclusively with computing, its use has now spread to numerous other disciplines. And finally, AI makes it possible to personalize learning by adapting content and providing feedback geared to a student's needs (Andrade, 2023). It also offers teachers numerous different ways of using it as a teaching aid (Vera, 2024), optimizes tasks and facilitates the creation of more enriching learning experiences (Parra-Taboada et al., 2024), although its integration poses challenges in things like the encouragement of ethical usage, the guaranteeing of equality of access, teacher capacitation and data protection, all of which underline the need to undertake research to develop AI-based teaching tools (Singh et al., 2025; Şahin Kölemen, 2024; Trejo-Quintana, 2023).

In recent years, several experiences have shown how positive the impact of such technologies has been in education. Blas Padilla and Jaén Martínez (2018), for example, found that Arduino projects using project-based learning (PBL) methodology produced better learning outcomes than traditional classes. Likewise, López Belmonte et al. (2019) used robotics to improve communication and the expression of feelings, obtaining high levels of participation and motivation. González Gallego et al. (2022) corroborated that including computational thinking in a syllabus raises students' interest. As an aid to the implementation of this process, block-based visual programming tools like Scratch allow for more intuitive experimentation (Sáez López & Buceta Otero, 2023) and, when used cross-sectionally, have proven to be very efficient in improving learning in subjects like mathematics (Molina-Ayuso, 2022). Within Spain, the Código Escuela 4.0 program, launched as part of the plan for recovery, transformation and resilience and the national artificial intelligence strategy (España Digital 2026, 2021), seeks to reinforce the corresponding competencies in teachers and students throughout the country. Despite the consensus regarding the positive impact of AI on the personalization of learning (Mora, 2024), the teaching of technology to students is not so easy. Few studies can be found which focus specifically on this aspect. Those that do include a proposal by Guerreiro-Santalla (2023) for an AI syllabus in pre-university education, in which the authors emphasize the crucial need for specific teacher training if AI is to be successfully integrated (Gamito et al., 2022; Gisbert Caudeli & Vela González, 2024).

After an exhaustive search in different databases, a significant knowledge gap was found to exist, with relatively few studies jointly addressing robotics, computational thinking and AI. Most of the studies found focus on only two of these three core elements. Examples of this include an analysis of AI in the learning of robotics by Pacha Chipantiza et al. (2024), a review of computational thinking in Latin America by Quiroz-Vallejo et al. (2021), and a study by Parra (2021) into inclusive robotics which covers computational thinking but not AI.

Considering such a dearth of knowledge, a systematic review constitutes an ideal way to synthesize all available evidence about how the three elements can all be integrated simultaneously (Marín-Juarros, 2022). It is an approach that makes it possible to identify patterns, tendencies and gaps in research, and which provides a solid basis for future work and for the development of empirically based teaching strategies.

The general objective of this paper is, therefore, to conduct a systematic review of literature relating to the integration and combined application of robotics, computational thinking and AI in education, in order to identify their impact on learning, the strategies used and the implementation challenges involved, while documenting the current state of research that jointly addresses those three elements. To this end, and adhering to the PICO framework, the following research questions were considered:

- To what extent are robotics, computational thinking and AI all integrated simultaneously in education?
- What teaching methodologies and strategies have been used in the teaching of this content?
- To what extent does the integration of AI, robotics and computational thinking improve results in comparison with traditional approaches to teaching?
- What are the main benefits and challenges that have been reported regarding the implementation of robotics, computational thinking and AI in education?

METHODOLOGY

This systematic review was carried out with strict adherence to the guidelines set out in the PRISMA statement (Page et al., 2021). This methodological approach was adopted in order to ensure a transparent, replicable, high-quality research process, minimizing the risk of bias and guaranteeing the reliability of the findings.

Search Protocol and Strategy

The process of searching for scientific literature was designed as two interactive phases. In the first phase, the exploratory search, broad searches were conducted to identify key words and assess the potential volume of documents. Carried out during the month of April 2025, this phase revealed a need to include terminological variations in English and Spanish. In the second phase, a systematic search carried out in May 2025, refined search chains began to be implemented in Web of Science, Scopus and Semantic Scholar, databases recognized for their wide coverage of peer-reviewed scientific publications and their impact in the scientific-academic domain. The search was optimized using Boolean operators (AND, OR), language variations, time and document type filters, synonyms and related terms:

- Web of Science: ("pensamiento computacional" AND "robótica educativa" AND "inteligencia artificial") OR ("computational thinking" AND "educational robotic" AND "artificial intelligence").
- Scopus: (TITLE-ABS-KEY ("computational thinking" OR "pensamiento computacional")) AND (TITLE-ABS-KEY("educational robotic" OR "robótica educativa")) AND (TITLE-ABS-KEY("artificial intelligence" OR "inteligencia artificial")) AND (TITLE-ABS-KEY(education OR learning OR teaching OR enseñanza OR aprendizaje)).
- Semantic Scholar: ("pensamiento computacional" AND "robótica educativa" AND "inteligencia artificial") OR ("computational thinking" AND "educational robotic" AND "artificial intelligence").

The application of these initial search strategies yielded a total of 126 results. A preliminary examination identified 5 articles that were duplicated in the databases. For the screening process and more rigorous selection of studies, clearly defined inclusion and exclusion criteria were then established (see [Table 1](#)).

Study Selection and Quality Assessment

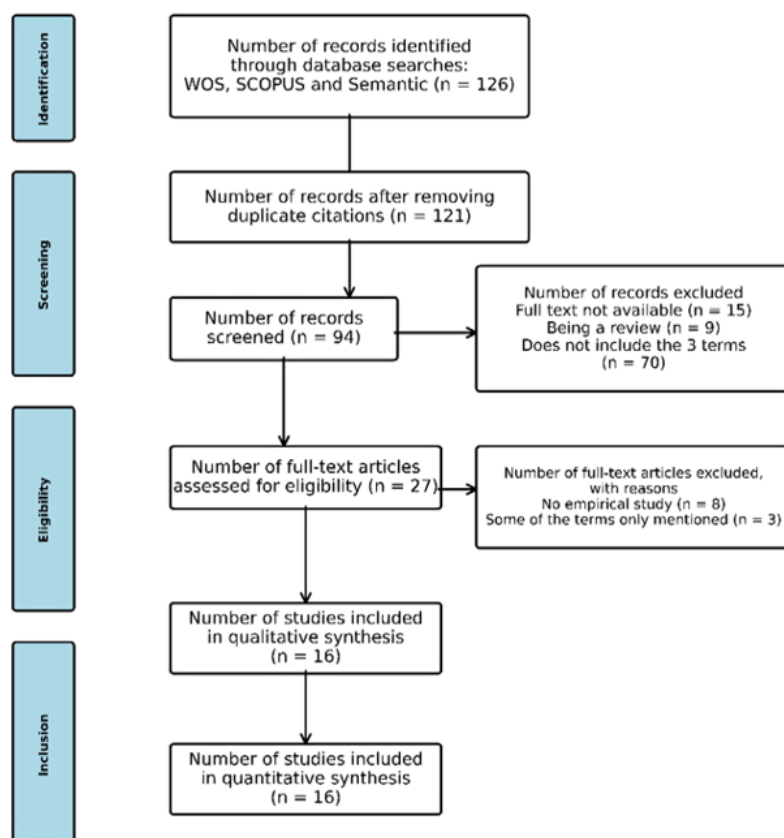
After the first stage of screening, it was found that a considerable number of articles (n = 70) did not meet the requirement to include all three main search terms. Another 15 articles were rejected because there was no access to their full texts, and 9 were rejected because they were systematic reviews.

A full reading of the potentially eligible remaining articles revealed that 3 of them only included mentions of one or several of the search terms, but that those terms lacked any real relevance in the main studies described. And finally, 8 more articles were rejected because they included no empirical studies, this being a fundamental pre-requisite for qualitative synthesis.

The whole selection and filtering process is detailed in the flow diagram shown in [Figure 1](#).

Table 1. Eligibility criteria for the selection of studies

Criteria	Inclusion	Exclusion
Type of publication	Original research articles published in scientific journals	Books, book chapters, summaries, editorials, conference abstracts without full text
Quality assessment	Peer-reviewed publications	Non-peer-reviewed publications, grey literature, doctoral theses
Thematic inclusion	Content which explicitly and jointly addresses all three key elements (computational thinking, robotics and artificial intelligence)	Studies which mention the three terms but do not really address their inclusion, or which focus on isolated elements
Time period	Publications between 2018 and 2025	Publications prior to 2018
Application context	Studies carried out in formal social sciences educational environments, including all levels of education (infants, primary, secondary, higher)	Implementations in non-educational environments (corporate or military training, non-formal education)
Study focus	Research with an empirical component or involving practical implementation in educational contexts	Articles focused exclusively on technical aspects unrelated to teaching; purely theoretical, unimplemented proposals
Accessibility	Documents with access to the full text via institutional subscriptions or open access	Documents with no possibility of accessing the full text
Study type	Original empirical studies with primary data	Systematic reviews, meta-analysis, narrative review studies

**Figure 1.** PRISMA flow diagram (Source: Authors' own elaboration based on Page et al. (2021))

Data Extraction and Analysis

Data were extracted using a structured matrix which included: bibliographical information (authors, year, journal), methodological characteristics (design, sample, and educational context), interventions implemented, main results and reported limitations. The bibliometric analysis was conducted using R software (version 4.3.2) with the Bibliometrix package (Aria & Cuccurullo, 2017), analyzing indicators for scientific production, collaboration between authors and institutions, and publications' evolution over time. Thematic content was analyzed using inductive coding, identifying recurring patterns in methodologies, teaching strategies, results and reported challenges.

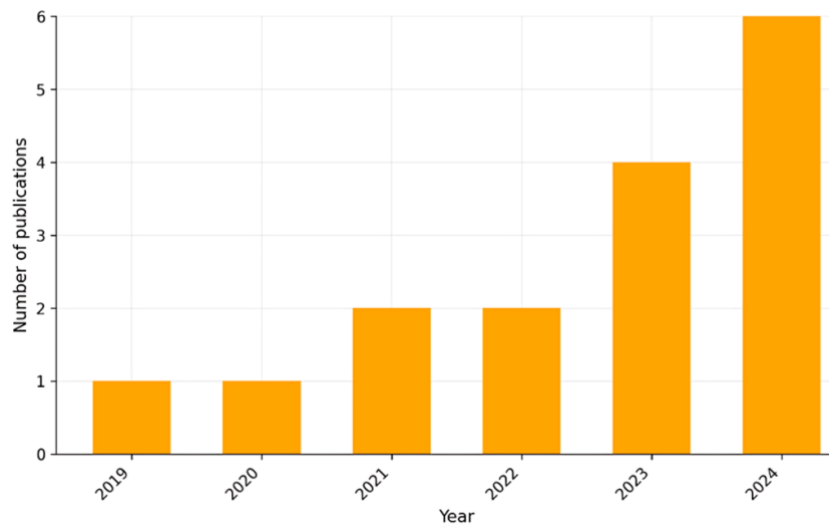


Figure 2. Distribution of publications by year (Source: Authors' own elaboration using Bibliometrix (R software v4.3.2))

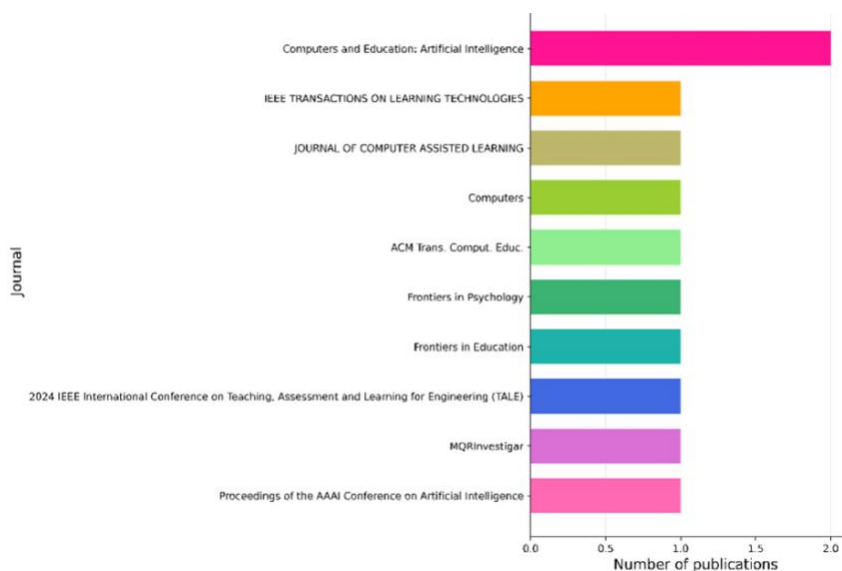


Figure 3. Most frequent journals (Source: Authors' own elaboration using Bibliometrix (R software v4.3.2))

ANALYSIS AND RESULTS

This systematic review revealed a noticeable knowledge gap in research into how educational robotics, computational thinking and AI are implemented in educational contexts. Despite the growing relevance of these technologies, the relative scarcity of scientific works which met the established inclusion criteria highlighted a clear need for future studies to explore this subject in greater depth.

Notwithstanding, analysis of the publications' distribution over time suggests that this is an emerging, rapidly expanding line of research. **Figure 2** illustrates an exponential increase in scientific production, which rose from one single article in 2019-2020 to 4 publications in 2023 and 6 in 2024. This represents an increase of 500% over the 5-year period analyzed. This upward trend, with 62.5% of the studies ($n = 10$) being published in 2023-2024, is indicative of an emerging field of study in a phase of consolidation. Growth rate analysis predicts a possible doubling of publications by 2025-2026, subject to future validation.

The articles analyzed were spread among different education, technology and social sciences journals. Two of them, published in 2021 and 2023, appeared in the "Computers and Education: Artificial Intelligence" journal. **Figure 3** and **Figure 4** show the journals in which papers were most frequently published and detail

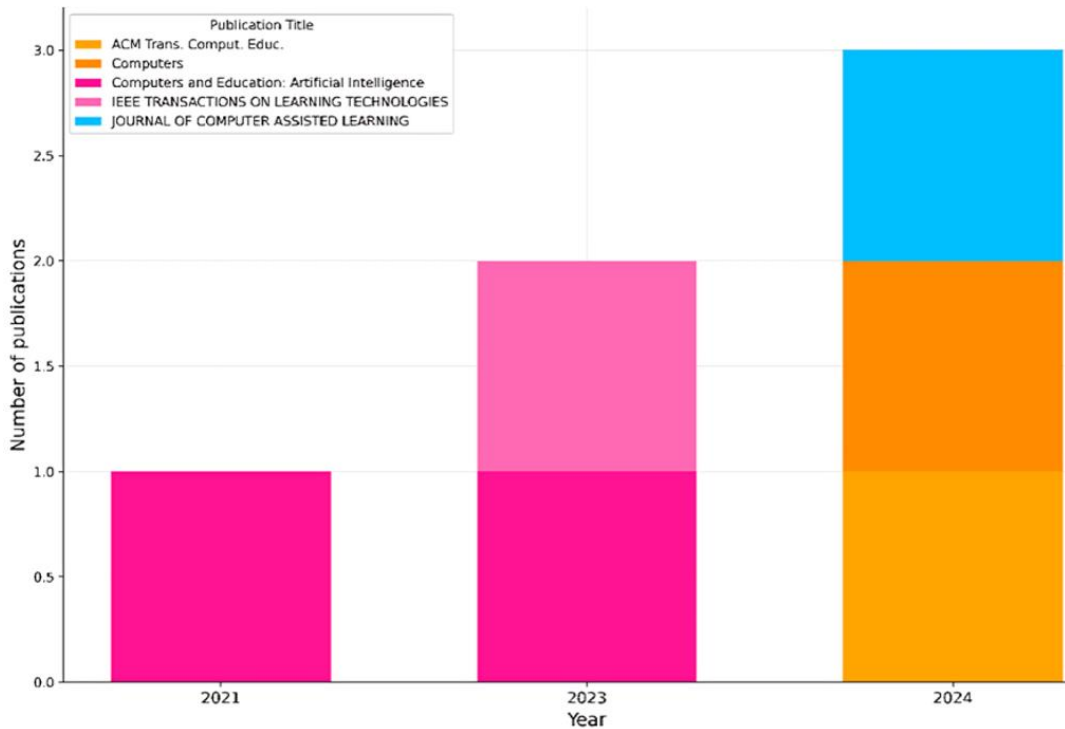


Figure 4. Publications by journal over time (Source: Authors' own elaboration using Bibliometrix (R software v4.3.2))

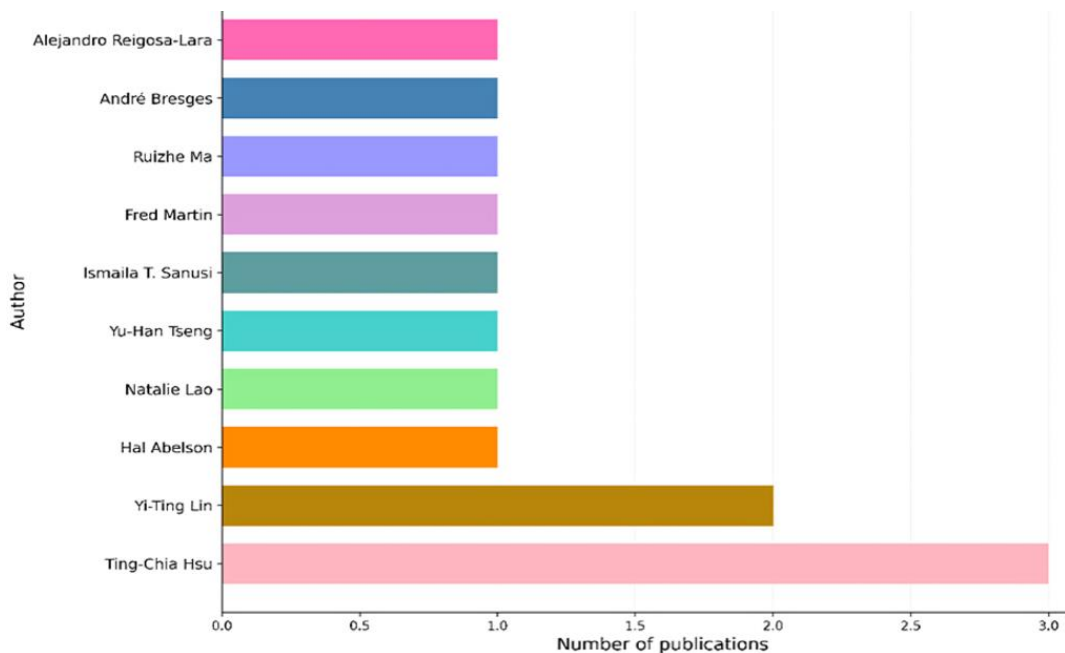


Figure 5. Most frequent authors (Source: Authors' own elaboration using Bibliometrix (R software v4.3.2))

how the number of articles published evolved over time. It can be seen that several journals have published works on the subject, although the number of articles published in each one is generally low.

Figure 5 and **Figure 6** show the most frequently appearing authors in the publications analyzed, together with a heat map of the most productive authors each year. The concentrations of authorship suggest the existence of consolidated research hubs in Asian institutions, revealing an unequal distribution of scientific production between different regions.

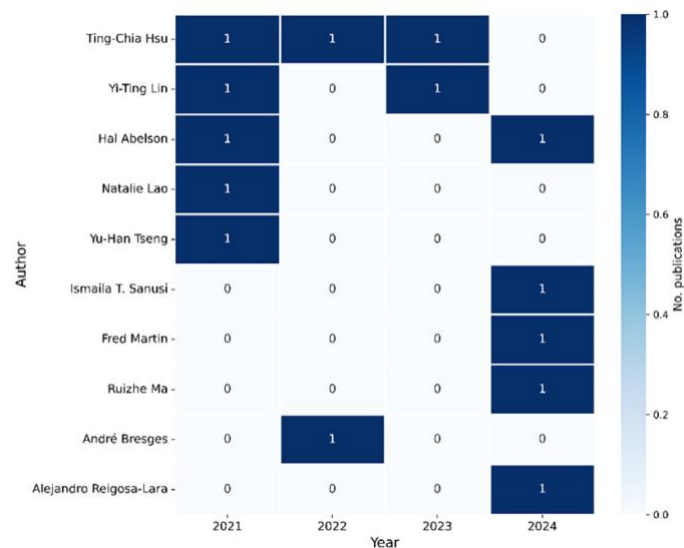


Figure 6. Heat map of authors (Source: Authors' own elaboration using Bibliometrix (R software v4.3.2))

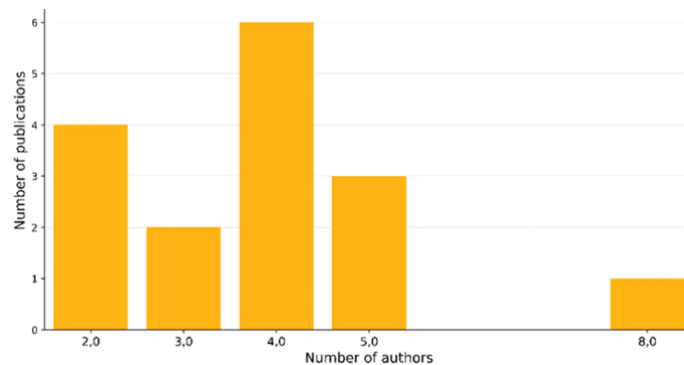


Figure 7. Distribution of articles by number of authors (Source: Authors' own elaboration using Bibliometrix (R software v4.3.2))

The distribution of articles by number of authors, with an average of 3.81 authors per article, and the co-authorship network (**Figure 7** and **Figure 8**), also indicate the existence of active research hubs where small groups of authors account for a significant amount of the total production.

Co-authorship network shows that collaborative research is organized mainly around institutions in Asia, Latin America, and Europe, with this line of research being shaped by emerging international connections.

Word cloud analysis of titles and keyword co-occurrence structures (see **Figure 9** and **Figure 10**) highlighted the prominence of terms like “AI”, “education”, “robotic”, “artificial”, “intelligence”, “computational”, “thinking”, “learning”, “training”, “teaching”, and “curriculum”.

Figure 9 and **Figure 10** also visually depict the close conceptual relationship between most of these terms in the literature reviewed. The frequency of keywords per year in the titles (**Figure 11**) suggests that these terms are gradually taking on greater importance over time, from the simple introduction of the technologies in school environments through to their inclusion in syllabuses and the pedagogical assessment of their impact.

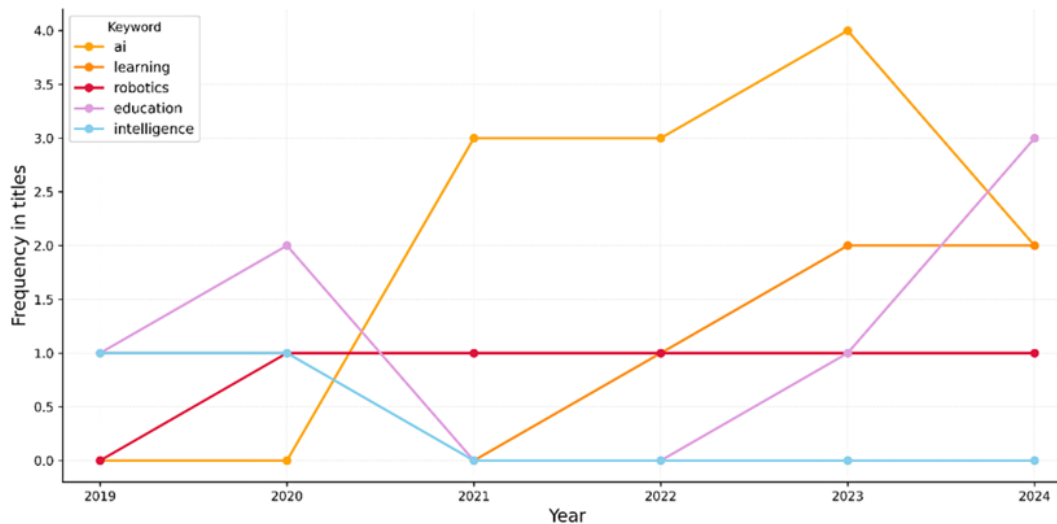


Figure 11. Keyword frequency by year in titles (Source: Authors' own elaboration using Bibliometrix (R software v4.3.2))

Table 2. Concept clusters

Documents	dim1	dim2	contrib	TC	Cluster
ai	-0.99	-0.63	49.98	82	3
artificial	1.60	0.02	17.18	71	3
children	-0.35	-0.41	29.85	54	3
coding	0.51	-0.66	14.81	78	1
computational	-0.06	1.45	21.69	4	3
courses	-0.02	-0.34	2.52	32	2
curriculum	-0.30	-0.28	18.81	65	2
development	0.11	-0.58	4.20	75	2
early	0.47	0.32	6.35	17	1
education	0.71	0.35	46.99	64	2
educational	0.35	-0.21	15.80	74	3
engagement	-0.85	0.06	40.20	1	1
intelligence	1.69	0.28	24.58	61	2
learning	-1.23	0.99	47.13	21	2
machine	-0.96	-0.39	40.17	14	2
robotics	0.67	-0.16	28.37	84	3
robots	0.20	-0.71	1.95	58	2
school	-1.09	-0.33	16.68	9	2
schools	0.57	-0.60	41.98	24	2
self	0.29	0.34	49.89	70	2
skills	0.11	0.77	17.35	47	1
students	-1.22	0.02	2.89	71	2
teaching	0.13	-0.72	45.22	8	2
thinking	-0.16	1.19	4.68	93	3
training	0.22	0.23	42.80	81	2
use	-0.39	-0.02	8.79	38	3

To identify the predominant thematic areas, the keywords of the selected articles were subjected to multiple correspondence analysis, a technique which makes it possible to display links between categorical variables in a small dimensional space (Greenacre, 2017). The resulting dimensions (dim1 and dim2) represent the major axes that explain the greatest amount of data variability, while the contribution value (contrib) indicates the relative weight of each term in the cluster configuration.

This analysis made it possible to identify three main thematic groups based on the conceptual proximity of the terms in [Table 2](#) and [Figure 12](#).

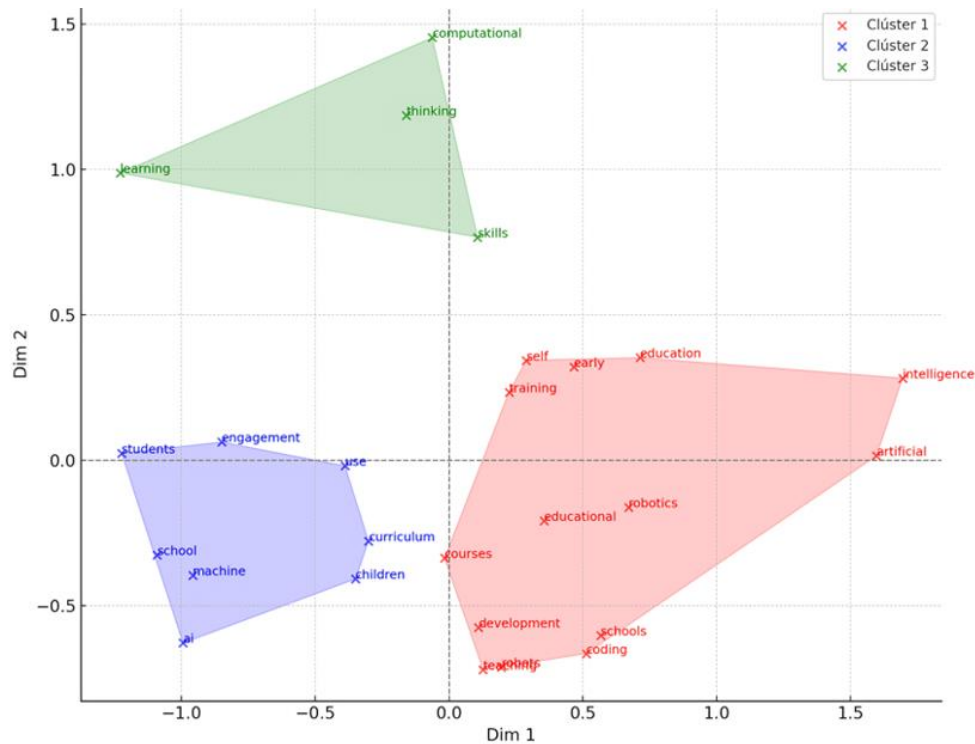


Figure 12. Map of concept clusters (Source: Authors' own elaboration using Bibliometrix (R software v4.3.2))

Analysis of the three thematic clusters shows that cluster 1 (emerging technologies) includes keywords like 'coding', 'early' and 'skills', and focuses on programming and the development of computational skills at early ages. Cluster 2 (educational designs with AI, robotics and computational thinking) includes words like 'intelligence', 'education', 'students', 'curriculum' and 'machine', and groups together studies into the implementation and impact of educational designs. The studies selected here often adopted quasi-experimental approaches. Cluster 3 (syllabus strategies for technological integration) includes keywords like 'AI', 'computational', 'thinking', 'robotics' and 'children', and addresses strategies for implementing AI, robotics, and computational thinking in education, mainly through the use of case studies.

Within cluster 1 (emerging technologies), "Exploring computational thinking skills training through augmented reality and AIoT learning" (Lin et al., 2021) was an experimental study which used augmented reality in AIoT courses to cultivate computational thinking skills. This initiative resulted in improved problem solving and planning. Williams et al. (2019) designed and evaluated an AI syllabus involving social robots for early childhood education. The study demonstrated that children in infant schools are able to understand basic AI concepts through the use of constructivist activities. Lescano-Veloz et al. (2024) conducted a quantitative study which assessed the impact of emerging technologies on the teaching of robotics, and reported significant improvements in comprehension, interest and the solving of complex problems. And finally, an experimental study by Su et al. (2024) comparing cooperative games with direct instruction in AI education showed that both approaches improve cognitive skills in early childhood education, although each one has its own unique strengths.

In cluster 2 (educational designs with AI, robotics, and computational thinking), a paper by Hsu et al. (2021) entitled "Behavioral-pattern exploration and development of an instructional tool for young children to learn AI" analyzed behavior patterns in primary school children learning AI using instructional tools and was able to identify behavior that predicted academic performance. Gaur and Kalita (2024) carried out two case studies which showed the positive impact of educational robots and AI on students, reporting significant improvements in STEM knowledge and cross-sectional skills. Sanusi et al. (2024) conducted a qualitative study to evaluate an ethical AI syllabus for secondary school students, showing improvements in AI knowledge through the use of innovative tools. Lu and Fan (2023) developed and evaluated a machine learning course based on weather forecasting for baccalaureate students, using Python and practical projects to achieve improved AI comprehension and computational thinking. Hsu and Chen (2022) assessed student commitment

using voice commands to control robot cars in a computational thinking board game, showing that learning and creative thinking can be improved by including AI in gamified activities, while a paper by Hsu et al. (2023) entitled “The artificial intelligence learning anxiety and self-efficacy of in-service teachers taking AI training courses” highlighted the need for training in AI.

In cluster 3 (syllabus strategies for technological integration), Mamatnabiyev et al. (2024) proposed a holistic approach using an open-source educational robot for multiple computer science courses, an initiative which proved to be educationally effective. Henze et al. (2022) studied the inclusion of STEAM, robotics, AI and sustainable development in teacher training, demonstrating a positive trend towards using the STEAM-6E model (engage, explore, explain, engineer, enrich, evaluate), model as a basis for the adoption of digital education tools. In “Robobo SmartCity” Naya-Varela et al. (2023) presented a self-driving-based educational model for teaching computational intelligence and AI, successfully validating the proposal with European students. Ferrari et al. (2020) conducted a qualitative exploratory study into the use of educational robots for teaching AI in schools. This proposal identified priorities for the training of digitally literate citizens using constructionist methodologies incorporating ethical and reflective elements. Lazarin et al. (2023) developed an educational tool kit for AI teaching using robotic agents, simplifying access to complex technologies by means of standardized prototypes. This tool was positively assessed in acceptance tests carried out at different levels of education. And another paper, “Robots at schools: Telerobotics, coding and teaching embodied artificial intelligence”, by Ponticorvo and Dell’Aquila (2024), described three European projects in which robots were used in schools for different educational purposes (inclusive telepresence, collaborative programming, and the teaching of AI). This study demonstrated the versatility and effectiveness of educational robotics.

To synthesize the key aspects of the articles reviewed, data available at <http://bit.ly/4njFTV6> contains a comprehensive matrix summarizing relevant information about each study, including title, authorship, sample population, methodological design, interventions implemented, main results, conclusions and reported limitations. This systematic synthesis facilitates comparisons between the studies and provides a basis for subsequent thematic analysis.

DISCUSSION

Robotics, computational thinking and AI are now being implemented at all levels of education, from infant schools to university and even on teacher training courses. The articles reviewed show how approaches and content can be adapted depending on participants’ ages and levels and reflect the gradual inclusion of these elements in school syllabuses in numerous countries.

The empirical evidence presented attests to significant improvements in different areas of learning. Authors have reported improvements in technical knowledge, self-sufficiency, problem solving, and interest in STEM disciplines (Gaur & Kalita, 2024), together with growth in students’ familiarity with AI and the successful involvement of participants with no previous experience in the use of emerging technologies (Sanusi et al., 2024). The research carried out has also identified different learning behavior patterns, with a trend towards experimentation and execution after having obtained simulated results (Hsu et al., 2021), and the exercise of computational thinking skills has been seen to have positive effects in areas like creativity, logical reasoning and problem solving (Lin et al., 2021). The findings indicate not only a higher level of knowledge acquisition and a significant increase in student commitment to subject matter when using robotics (Mamatnabiyev et al., 2024), but also improved understanding of robotic concepts, greater interest and the easier solving of complex problems to the use of emerging digital technologies (Lescano-Veloz et al., 2024).

The teaching methodologies and strategies employed in the studies analyzed are varied but they all have one thing in common: they are all active and aligned with a constructivist model of learning based on the extensive use of digital tools. The methodologies adopted include cooperative and collaborative learning, both of which encourage interaction and teamwork between students and feature prominently in the proposals implemented. PBL typically involves the practical application of concepts to real scenarios, while the STEAM-6E model, with its highly innovative approach and significant results, is exemplified in studies like “Developing a weather prediction project-based machine learning course in facilitating AI learning among high

school students" (Lu & Fan, 2023) and "How might we raise interest in robotics, coding, artificial intelligence, STEAM and sustainable development in university and on-the-job teacher training?" (Henze et al., 2022). Game-based learning (GBL) and gamification constitute complementary strategies which provide students with a fun, motivating perspective.

It should be mentioned that most of the studies analyzed implemented a combination of teaching methodologies. This hybrid approach significantly enriches the teaching-learning process, making it possible to adapt content more efficiently to different learning styles and different educational environments.

With regard to teaching strategies, the use of manipulative tools like educational robots or robotics kits (both commercial and open source) is of particular interest. Block-based visual programming in environments like Scratch is especially effective in early levels of education, while textual programming in languages like Python is better suited to higher levels. These strategies are complemented by mobile phone and tablet applications and by emerging technologies like AI, virtual reality and augmented reality to visualize abstract concepts. Another hybrid approach has been consolidated which combines "plugged" activities, requiring the use of digital devices, with "unplugged" activities that can be used to work on technological concepts without actually using any technology: for example, using board games to develop computational thinking (Hsu et al., 2021).

CONCLUSIONS

This systematic review, based on 16 empirical studies involving the combined integration of robotics, computational thinking and AI, revealed an emerging field of research currently in the process of consolidation (with a growth of 500% in publications in the period 2019-2024). The analysis conducted identified three main thematic clusters: emerging technologies, educational designs, and syllabus strategies. It also indicated a predominance of active methodologies (PBL 62%; cooperative learning 75%; STEAM 38%). Comparative studies documented significant improvements in cognitive competencies ($d = 0.65-0.89$), motivation (87% of students showed greater interest), and collaborative skills (53% improvement), making the incorporation of these three elements a promising teaching strategy for the development of 21st century competencies. The difficulty of finding studies which met the pre-established inclusion criteria highlighted the knowledge gap that currently exists in research in this field. This lack of studies underlines the need to conduct rigorous research which will not only assess the effectiveness of the elements in question but also provide a solid basis for future work and encourage the development of efficient teaching strategies.

The research questions governing this study were crucial for achieving the overall objective. With regard to the first question, the evidence gathered indicates a growing combined presence of robotics, computational thinking and AI in school syllabuses worldwide—something corroborated by growing interest in both the study and the practical application of those elements. Implementation initiatives reflect a gradual, contextualized refinement in terms of approach and content, suggesting a conceptual and methodological maturing of this field of interest. The simultaneous integration of the three technologies is an emerging phenomenon which moves beyond the piecemeal inclusion of digital tools and constitutes an integrated educational ecosystem capable of driving development of 21st century competencies.

Regarding the teaching methodologies and strategies that have been used to teach this content, the studies analyzed revealed a rich variety of approaches, including STEAM, PBL, cooperative and collaborative learning, GBL and gamification. One of the most interesting strategies is the use of a hybrid approach combining "plugged" activities involving digital devices and "unplugged" activities involving no technology, the two types of activity being strategically differentiated depending on the level of education. This approach employs everything from advanced technological tools like robotics kits, programming languages and mobile devices to more traditional resources like board games and activities for developing computational thinking. It is important to note that the combination of such methodologies and strategies enriches and diversifies the scope of teaching proposals, making it possible to generate more effective learning experiences geared towards heterogeneity in educational environments.

Returning to the research questions, the results obtained when comparing educational approaches that incorporate the emerging technologies with traditional teaching methods reveal that the more innovative proposals have a positive impact. The implementation of educational robots and AI favorably affects the

development of cognitive, technical and cross-sectional skills, significantly stimulating students' interest and comprehension through an eminently practical, recreational approach (Gaur & Kalita, 2024). Moreover, the application of active methodologies and the use of digital resources not only raise students' levels of commitment, motivation and active participation but also encourage the development of 21st century skills like critical thinking, creativity, teamwork and problem solving. The proposals reviewed facilitate a closer connection between abstract concepts and real applications, allowing greater personalization of learning and fomenting experiential learning directly linked to everyday life situations. This contrasts with the passive, and sometimes decontextualized, approaches characteristic of traditional methodologies.

One crucial benefit of incorporating robotics, computational thinking and AI into education is that it offers students better preparation for entry into the labor market. As pointed out by Lescano-Veloz et al. (2024), the emerging digital technologies significantly improve theoretical comprehension, practical application, interest and problem-solving skills. This underscores the need to include such technologies in education syllabuses as a means of cultivating digitally literate citizens and ensuring that future generations are effectively prepared for employment (Ferrari et al., 2020). Specific benefits have also been observed in academic performance, in the development of key skills like computational thinking, critical thinking, and self-regulation, and in the practical application of theoretical concepts. Driven by curiosity and innovation, students show greater motivation and participate more actively, and this contributes to a higher degree of autonomy. These types of teaching proposals also encourage the development of social and communication skills, again fostering experiential learning linked to everyday situations.

Despite its clear benefits, however, the implementation of the emerging technologies does pose some major challenges. These include the need for specialized teacher training to ensure the provision of professionals competent in their use—including emerging competencies such as the design of effective AI prompts (García-Beltrán, 2026)—, limitations in technological infrastructure, which requires appropriate equipment and constant upgrading; the digital gap and inequality in access to the technologies; the limited time periods in which teachers can implement the proposals; the inherent complexity of assessing this type of content—for which validated instruments to measure the academic use of generative AI are now available (Trejo-Trejo & Gordillo-Espinoza, 2026)—and the need for specialized technical support. All of these are serious obstacles to effective implementation.

The trade-off between benefits and challenges is still clearly weighed towards benefits, although the sustained success of these types of teaching proposals over time requires a holistic implementation covering not only the technical aspects involved but also pedagogical, ethical and training considerations. To ensure maximum efficiency, it is also important to consider the opinions, experience, and needs of all the actors involved in education.

The main limitation of this review concerns the participant samples used in some of the studies analyzed. The presence of small samples in some works emphasizes the need to carry out more studies into this subject and to replicate those with insufficient samples in order to validate their findings and robustly assess the effectiveness of their teaching proposals. Another limitation was the scarcity of studies that jointly addressed all three elements—robotics, computational thinking, and AI. This scarcity, however, was interpreted as a research opportunity, highlighting the urgent need to explore this emerging subject in greater depth in future studies.

Author contributions: **M.S.-H.:** conceptualization, methodology, investigation, formal analysis, writing – original draft; **M.A.-M.:** supervision, writing – review & editing, validation; **M.S.-H., A.M.O.-C. & M.A.-M.:** data curation, formal analysis, visualization; **M.S.-H., J.R.-M & A.M.O.-C:** supervision, writing – review & editing, project administration. All authors sufficiently contributed to this study and approved the final version of the article.

Funding: The authors received no financial support for the research and/or authorship of this article.

Ethics declaration: This study is a systematic review of published literature and did not involve direct interaction with human participants. Therefore, no informed consent or ethical approval was required. All data analyzed were extracted from publicly available peer-reviewed publications.

AI statement: The authors declare that no generative AI or AI-based tools were used in the preparation, writing, or production of this manuscript.

Declaration of interest: The authors declared no competing interests.

Data availability: Data generated or analyzed during this study are available from the authors on request.

REFERENCES

- Andrade, E. L. M. (2023). Aplicación de la inteligencia artificial en la educación superior [Application of artificial intelligence in higher education]. *DOCERE*, 29, Article 29. <https://doi.org/10.33064/2023docere295075>
- Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, 11(4), 959-975. <https://doi.org/10.1016/j.joi.2017.08.007>
- Barrera-Pacheco, J. A. (2023). La robótica educativa como estrategia didáctica [Educational robotics as a teaching strategy]. *Vida Científica Boletín Científico de la Escuela Preparatoria No. 4*. 11(22), 15-17. <https://doi.org/10.29057/prepa4.v11i22.11013>
- Blas Padilla, D., & Jaén Martínez, A. (2018). Experiencia didáctica con Arduino: El aprendizaje basado en proyectos como metodología de trabajo en el aula de secundaria [Educational experience with Arduino: Project-based learning as a working methodology in the secondary school classroom]. *Hekademos: Revista Educativa Digital*, 25, 73-82. <https://dialnet.unirioja.es/servlet/articulo?codigo=6789674>
- Carrillo, J. J. M., Solórzano, L. E. Z., Muñoz, R. A. V., & Franco, F. X. P. (2024). Alfabetización tecnológica: Retos para una población competitiva y productiva [Technological literacy: Challenges for a competitive and productive population]. *Maestro y Sociedad*. <https://maestroysociedad.uo.edu.cu/index.php/MyS/article/view/6418>
- España Digital 2026. (2021). Programa Código escuela 4.0 [School code 4.0 program]. *España Digital*. <https://bit.ly/4dvZMwv>
- Ferrari, L., Macaudo, A., Soriani, A., & Russo, V. (2020). Educational robotics and artificial intelligence education: What priorities for schools? *Form@re-Open Journal per la Formazione in Rete*, 20(3), 68-85. <https://doi.org/10.13128/form-10038>
- Gamito, R., Aristizabal, P., Basasoro, M., & León, I. (2022). El desarrollo del pensamiento computacional en educación: Valoración basada en una experiencia con Scratch [The development of computational thinking in education: An assessment based on an experience with Scratch]. *Innoeduca. International Journal of Technology and Educational Innovation*, 8(1), 59-74. <https://doi.org/10.24310/innoeduca.2022.v8i1.12093>
- García-Beltrán, E. (2026). No es magia, es prompting: El diseño de prompts como competencia emergente en la formación docente. Un estudio desde el modelo CRETA+ R [It's not magic, it's prompting: Designing prompts as an emerging competency in teacher training. A study based on the CRETA+R model]. *Pixel-Bit: Revista de Medios y Educación*, 75, Article 6. <https://doi.org/10.12795/pixelbit.115487>
- Gaur, A., & Kalita, K. (2024). Impact of enhanced learning approaches on STEM-focused education for school children in assam, India. In *Proceedings of the 2024 IEEE International Conference on Teaching, Assessment and Learning for Engineering* (pp. 1-8). IEEE. <https://doi.org/10.1109/TALE62452.2024.10834323>
- Gisbert Caudeli, V., & Vela González, M. (2024). Inteligencia artificial en el aula de música: Experiencia y percepción del profesorado especialista en educación secundaria [Artificial intelligence in the music classroom: Experiences and perceptions of specialist secondary school teachers]. *Educatio Siglo XXI*, 42(3), 97-114. <https://doi.org/10.6018/educatio.623181>
- González Gallego, S., Santana Coll, A., Varea Carballo, R., Alcalde Rodríguez, A., García Rodríguez, O., Pérez Hernández, H., Rosales Rodríguez, C. B., Bacallado Marrero, M. Á., López Navarro, R., Garriga i Cabo, C., Pérez Salazar, M. L., Padrón Álvarez, J. R., Álamo Rosales, J., Zapatera Llinares, A., & Quevedo Gutiérrez, E. G. (2022). Lanzamiento de proyecto de centro de pensamiento computacional en educación secundaria: Lecciones aprendidas y planificación futura partiendo del Real Decreto de enseñanzas mínimas de la LOMLOE [Launch of a project for a computational thinking center in secondary education: Lessons learned and future planning based on the Royal Decree on minimum educational standards of the LOMLOE]. *FPIEM: Formación del Profesorado e Investigación en Educación Matemática*, 14, 137-171. <https://dialnet.unirioja.es/servlet/articulo?codigo=8842647>
- González-Fernández, M. O., González-Flores, Y. A., & Muñoz-López, C. (2021). Panorama de la robótica educativa a favor del aprendizaje STEAM [Overview of educational robotics in support of STEAM learning]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*, 18(2), Article 2301. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2021.v18.i2.2301
- Greenacre, M. (2017). *Correspondence analysis in practice* (3rd ed.). Chapman and Hall/CRC. <https://doi.org/10.1201/9781315369983>

- Guerreiro-Santalla, S. (2023). *Desarrollo de un plan de estudios de inteligencia artificial para la educación preuniversitaria en Europa* [Development of an artificial intelligence curriculum for pre-university education in Europe] [Doctoral thesis, Universidade da Coruña]. <http://hdl.handle.net/2183/34544>
- Henze, J., Schatz, C., Malik, S., & Bresges, A. (2022). How might we raise interest in robotics, coding, artificial intelligence, steam and sustainable development in university and on-the-job teacher training? *Frontiers in Education*, 7, Article 872637. <https://doi.org/10.3389/feduc.2022.872637>
- Hsu, T.-C., & Chen, M.-S. (2022). The engagement of students when learning to use a personal audio classifier to control robot cars in a computational thinking board game. *Research and Practice in Technology Enhanced Learning*, 17, Article 27. <https://doi.org/10.1186/s41039-022-00202-1>
- Hsu, T.-C., Abelson, H., Lao, N., Tseng, Y.-H., & Lin, Y.-T. (2021). Behavioral-pattern exploration and development of an instructional tool for young children to learn AI. *Computers and Education: Artificial Intelligence*, 2, Article 100012. <https://doi.org/10.1016/j.caeai.2021.100012>
- Hsu, T.-C., Hsu, T.-P., & Lin, Y.-T. (2023). The artificial intelligence learning anxiety and self-efficacy of in-service teachers taking AI training courses. In *Proceedings of the 2023 International Conference on Artificial Intelligence and Education* (pp. 97-101). <https://doi.org/10.1109/ICAIE56796.2023.00034>
- Jiménez, Ó. G. (2022). Robótica y LOMLOE: Revisión sistemática de la robótica como herramienta inclusiva [Robotics and LOMLOE: A systematic review of robotics as an inclusive tool]. *HUMAN REVIEW. International Humanities Review/Revista Internacional de Humanidades*, 13(1), Article 1. <https://dialnet.unirioja.es/servlet/articulo?codigo=8839690>
- Lazarin, N. M., Pantoja, C. E., & Viterbo, J. (2023). Towards a toolkit for teaching AI supported by robotic-agents: Proposal and first impressions. In *Proceedings of the Workshop Sobre Educação em Computação* (pp. 20-29). <https://doi.org/10.5753/wei.2023.229753>
- Lescano-Veloz, A. L., Amaiquema-Gil, S. B., Reigosa-Lara, A., & Tobar-Farias, G. W. (2024). Integración de tecnologías digitales emergentes para mejorar el proceso de enseñanza-aprendizaje en la asignatura de robótica en la formación tecnológica [Integration of emerging digital technologies to improve the teaching-learning process in the subject of robotics in technological training]. *MQRInvestigar*, 8(4), 247-274. <https://doi.org/10.56048/MQR20225.8.4.2024.247-274>
- Lin, Y.-S., Chen, S.-Y., Tsai, C.-W., & Lai, Y.-H. (2021). Exploring computational thinking skills training through augmented reality and AIoT learning. *Frontiers in Psychology*, 12, Article 640115. <https://doi.org/10.3389/fpsyg.2021.640115>
- López Belmonte, J., Pozo Sánchez, S., Vicente Bújez, M. R., & Díaz Mohedo, M. T. (2019). Herramientas robóticas para la dinamización de nuevos espacios educativos [Robotic tools for the revitalization of new educational spaces]. *Campus Virtuales*, 8(1), 63-73. <https://www.uajournals.com/ojs/index.php/campusvirtuales/article/view/392>
- Lu, W.-Y., & Fan, S.-C. (2023). Developing a weather prediction project-based machine learning course in facilitating AI learning among high school students. *Computers and Education: Artificial Intelligence*, 5, Article 100154. <https://doi.org/10.1016/j.caeai.2023.100154>
- Mamatnabiyev, Z., Chronis, C., Varlamis, I., Himeur, Y., & Zhaparov, M. (2024). A holistic approach to use educational robots for supporting computer science courses. *Computers*, 13(4), Article 4. <https://doi.org/10.3390/computers13040102>
- Marín-Juarros, V. I. (2022). La revisión sistemática en la investigación en tecnología educativa: Observaciones y consejos [Systematic reviews in educational technology research: Observations and advice]. *Revista Interuniversitaria de Investigación en Tecnología Educativa*, 13, 62-79. <https://doi.org/10.6018/riite.533231>
- Molina-Ayuso, Á. (2022). *Contribución del pensamiento computacional con Scratch al proceso de enseñanza y aprendizaje de las matemáticas* [Contribution of computational thinking with Scratch to the teaching and learning process of mathematics] [PhD thesis, Universidad de Córdoba]. <http://hdl.handle.net/10396/24462>
- Mora, F. F. B. (2024). Inteligencia artificial en la educación: Simplificación de los procesos de aprendizaje [Artificial intelligence in education: Simplifying learning processes]. *Ciencia Latina Revista Científica Multidisciplinar*, 8(4), 12700-12709. https://doi.org/10.37811/cl_rcm.v8i4.13468
- Naya-Varela, M., Guerreiro-Santalla, S., Baamonde, T., & Bellas, F. (2023). Robobo SmartCity: An autonomous driving model for computational intelligence learning through educational robotics. *IEEE Transactions On Learning Technologies*, 16(4), 543-559. <https://doi.org/10.1109/TLT.2023.3244604>

- Pacha Chipantiza, N. E., Barba Palma, H. M., Sevilla Morocho, L. E., Pacha Chipantiza, N. E., Barba Palma, H. M., & Sevilla Morocho, L. E. (2024). Análisis sistemático de integración de inteligencia artificial en el aprendizaje de la robótica en la educación secundaria [Systematic analysis of the integration of artificial intelligence in robotics learning in secondary education]. *Universidad, Ciencia y Tecnología*, 28(123), 111-121. <https://doi.org/10.47460/uct.v28i123.811>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Systematic Reviews*, 10(1), Article 89. <https://doi.org/10.1186/s13643-021-01626-4>
- Parra, J. R. (2021). Robótica para la inclusión educativa: Una revisión sistemática [Robotics for educational inclusion: A systematic review]. *RiiTE Revista Interuniversitaria de investigación en Tecnología Educativa*, 11, 150-171. <https://doi.org/10.6018/riite.492211>
- Parra-Taboada, M. E., Trujillo-Arteaga, J. C., Álvarez-Abad, D. R., Arias-Domínguez, A. S., & Santillán-Gordón, E. (2024). El impacto de la inteligencia artificial en la educación [The impact of artificial intelligence on education]. *Revista Científica Retos de la Ciencia*, 1(4), 169-181. <https://doi.org/10.53877/rc.8.19e.202409.14>
- Ponticorvo, M., & Dell'Aquila, E. (2024). Robots at schools: Telerobotics, coding and teaching embodied artificial intelligence. In *Proceedings of the 2024 9th International Conference on Information and Education Innovations* (pp. 1-6). <https://doi.org/10.1145/3664934.3664940>
- Quiroz-Vallejo, D. A., Carmona-Mesa, J. A., Castrillón-Yepes, A., & Villa-Ochoa, J. A. (2021). Integración del pensamiento computacional en la educación primaria y secundaria en Latinoamérica: Una revisión sistemática de literatura [Integration of computational thinking in primary and secondary education in Latin America: A systematic literature review]. *Revista de Educación a Distancia*, 21(68), Article 7. <https://doi.org/10.6018/red.485321>
- Sáez López, J. M., & Buceta Otero, R. (2023). El robot M bot para el aprendizaje de coordenadas Cartesianas en educación secundaria [The M bot robot for learning Cartesian coordinates in secondary education]. *Pixel-Bit: Revista de Medios y Educación*, (66), 271-301. <https://doi.org/10.12795/pixelbit.95617>
- Şahin Kölemen, C. (2024). Artificial intelligence technologies and ethics in educational processes: Suggested solutions and results. *Innoeduca. International Journal of Technology and Educational Innovation*, 10(2), 201-216. <https://doi.org/10.24310/ijtei.102.2024.19806>
- Sánchez, T. S., Sánchez, J. L. S., & Acosta, F. R. (2020). Influencia de la robótica educativa en la motivación y el trabajo cooperativo en educación primaria: Un estudio de caso [Influence of educational robotics on motivation and cooperative work in primary education: A case study]. *Innoeduca. International Journal of Technology and Educational Innovation*, 6(2), 141-152. <https://doi.org/10.24310/innoeduca.2020.v6i2.6779>
- Sanusi, I. T., Martin, F., Ma, R., Gonzales, J. E., Mahipal, V., Oyelere, S. S., Suhonen, J., & Tukiainen, M. (2024). AI MyData: Fostering middle school students' engagement with machine learning through an ethics-infused AI curriculum. *ACM Transactions on Computing Education*, 24(4), Article 55. <https://doi.org/10.1145/3702242>
- Singh, S., Singh, P., & Kaur, V. (2025). Understanding ChatGPT adoption among higher education students in Punjab, India: An application of the UTAUT2 model. *Innoeduca. International Journal of Technology and Educational Innovation*, 11(1), 5-28. <https://doi.org/10.24310/ijtei.111.2025.20219>
- Su, J., Yang, W., Yim, I. H. Y., Li, H., & Hu, X. (2024). Early artificial intelligence education: Effects of cooperative play and direct instruction on kindergarteners' computational thinking, sequencing, self-regulation and theory of mind skills. *Journal of Computer Assisted Learning*, 40(6), 2917-2925. <https://doi.org/10.1111/jcal.13040>
- Trejo-Quintana, J. (2023). Más preguntas que respuestas: La inteligencia artificial y la educación [More questions than answers: Artificial intelligence and education]. *Perfiles Educativos*, 45(Special), 43-55. <https://doi.org/10.22201/iisue.24486167e.2023.Especial.61690>

- Trejo-Trejo, G. A., & Gordillo-Espinoza, E. (2026). Validación de un instrumento para medir el uso académico de la IAGen en estudiantes universitarios [Validation of an instrument to measure the academic use of IAGen in university students]. *Pixel-Bit: Revista de Medios y Educación*, 75, Article 7. <https://doi.org/10.12795/pixelbit.117960>
- Trijueque, S. G., & Marañón, C. O. (2022). La Cuarta Revolución Industrial: Transformación digital como nuevo paradigma [The Fourth Industrial Revolution: Digital transformation as a new paradigm]. *Signo y Pensamiento*, 41. <https://doi.org/10.11144/Javeriana.syp41.crit>
- Vera, M. D. M. S. (2019). Computational thinking in educational environments: An approach from educational technology. *Research in Education and Learning Innovation Archives*, 23, 24-39. <https://doi.org/10.7203/realia.23.15635>
- Vera, M. D. M. S. (2024). La inteligencia artificial como recurso docente: Usos y posibilidades para el profesorado [Artificial intelligence as a teaching resource: Uses and possibilities for teachers]. *EDUCAR*, 60(1), 33-47. <https://doi.org/10.5565/rev/educar.1810>
- Williams, R., Park, H. W., Oh, L., & Breazeal, C. (2019). PopBots: Designing an artificial intelligence curriculum for early childhood education. *Proceedings of the AAAI Conference on Artificial Intelligence*, 33(1), 9729-9736. <https://doi.org/10.1609/aaai.v33i01.33019729>
- Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, 49(3), 33-35. <https://doi.org/10.1145/1118178.1118215>
- Zapata-Ros, M. (2015). Pensamiento computacional: Una nueva alfabetización digital [Computational thinking: A new digital literacy]. *Revista de Educación a Distancia*, 46. <https://dialnet.unirioja.es/servlet/articulo?codigo=5284113>

