JOURNAL OF NEW APPROACHES IN EDUCATIONAL RESEARCH
2023, VOL. 12, NO. 1, 171-197, e-ISSN: 2254-7339
https://doi.org/10.7821/naer.2023.1.1240

ORIGINAL

Analysing the Impact of Artificial Intelligence and Computational Sciences on Student Performance: Systematic Review and Meta-analysis

Inmaculada García-Martínez[1], José María Fernández-Batanero[2], José Fernández-Cerero[2] and Samuel P. León[3]

[1]Department of Didactics and School Organization, University of Granada, Spain
[2]Department of Didactics and School Organization, University of Seville, Spain
[3]Department of Pedagogy, University of Jaén, Spain

ABSTRACT

Artificial intelligence (AI) and computational sciences have aroused a growing interest in education. Despite its relatively recent history, AI is increasingly being introduced into the classroom through different modalities, with the aim of improving student achievement. Thus, the purpose of the research is to analyse, quantitatively and qualitatively, the impact of AI components and computational sciences on student performance. For this purpose, a systematic review and meta-analysis have been carried out in WOS and Scopus databases. After applying the inclusion and exclusion criteria, the sample was set at 25 articles. The results support the positive impact that AI and computational sciences have on student performance, finding a rise in their attitude towards learning and their motivation, especially in the STEM (Science, Technology, Engineering, and Mathematics) areas. Despite the multiple benefits provided, the implementation of these technologies in instructional processes involves a great educational and ethical challenge for teachers in relation to their design and implementation, which requires further analysis from the educational research. These findings are consistent at all educational stages.

Keywords ARTIFICIAL INTELLIGENCE, LEARNING ACHIEVEMENT, EDUCATION, TEACHING METHODS, EDUCATIONAL IMPROVEMENT

Check for updates

Received 2022-09-24
Revised 2022-10-14
Accepted 2022-12-05
Published 2023-01-15

Corresponding Author
Inmaculada García-Martínez,
igmartinez@ugr.es

Departamento de Didáctica y Organización Escolar. Facultad de Ciencias de la Educación. Campus de Cartuja s/n 18071 Granada, Spain.

DOI https://doi.org/10.7821/naer.2023.1.1240
Pages: 171-197

Funding: Spanish State Research Agency, Spain (Award:PID2019-108230RB-I00)

1 INTRODUCTION

Nowadays, society is becoming increasingly oriented towards a massive process of technologicalisation in all spheres (political, economic, educational, social, etc.). This trend of adaptating to new technological interaction communities has created a variety of technologies that allow communication with the user, called "virtual assistants", which use computer algorithms to emulate human intelligence so that users have the feeling that they are interacting with another person. This concept is known as "artificial intelligence" (AI) (Ocaña,

How to cite this article (APA): García-Martínez, I., Fernández-Batanero, J. M., Fernández-Cerero, J., & León, S. P. (2023). Analysing the Impact of Artificial Intelligence and Computational Sciences on Student Performance: Systematic Review and Meta-analysis. *Journal of New Approaches in Educational Research, 12(1)*, 171-197. doi: 10.7821/naer.2023.1.1240

Valenzuela, & Garro, 2019; Yang, Zhuang, & Pan, 2021). In educational environments, AI has taken special interest, given the high possibilities of communication that are established between teachers and students when using virtual information assistants, since from its execution there is a simulation of responses that approach a human conversation and, as the tool is used, the interaction with the user is learned and recognised intuitively. Nevertheless, in the current global context of the technological revolution, there are human qualities that cannot yet be reproduced by AI, such as creativity or the ability to produce new ideas or to improvise and constantly evolve. In this regard, current trends in AI and computational science are moving towards human-centred AI, that considers people's characteristics and contexts to reduce the biases that may be associated with the management and processing of the algorithms that support it (Yang et al., 2021). According to UNESCO (2019), the link between AI and education consists of three areas: learning with AI (using AI tools in the classroom), learning about AI (its technologies and techniques) and preparing for AI (enabling all citizens to understand the potential impact of AI on human life). It also believes that AI has the potential to address some of the biggest challenges facing education today, namely, to develop innovative teaching and learning practices guided by the fundamental principles of inclusion and equity while helping to accelerate progress towards SDG 4.

Thus, AI has a strong potential to accelerate the process of realisation and development of the global goals around education by reducing barriers to access to learning, by automating management processes, and by optimising methods to improve student performance and, as a result, learning outcomes (Moreno, 2019).

In short, AI as a technological tool applied to education may contribute innovative methods and ways with the use of ICT that improve the teaching and learning process from the perspective of the student and the teacher.

1.1 Artificial Intelligence in the Educational Context

The educational field is constantly changing and adapting to new generations and their educational needs (Halili, 2019). If we consider that all these developments go in parallel with technological advances, we can say that the speed at which education is being updated may be the fastest ever (Harrison, 1986). Although these advances are studied from their many forms, they all have a common factor: AI.

To address the concept of AI, as discussed above, it must be understood to include any resource or machine that carries out human work. Humans create these machines to mechanise the tasks they perform every day, with the purpose of accomplishing more in less time. Popenici and Kerr (2017) define it as computing systems that can engage in similar processes to the human ones, such as learning, adapting, synthesising, self-correcting and using data for complex processing tasks. More specifically in education, educational artificial intelligence (EAI) refers to the use of AI to support personalised and automated feedback and guidance in the educational field Song and Wang (2020).

The growing demand in education in recent years has given rise to a thriving new field of research which integrates AI and education, which has resulted in an expansion of the existing literature on EAI. Furthermore, and updating this terminology, EAI is related to different fields, such as robotics (Jawaid et al., 2020), applications for smart devices (Petko, Schmid, Müller, & Hielscher, 2019), electronic devices (Pyörälä et al., 2019), e-learning (Reister & Blanchard, 2020; Singer-Brodowski, Brock, Etzkorn, & Otte, 2019), or virtual (VR) and augmented reality (AR) (Bower, Dewitt, & Lai, 2020; Kavanagh, Luxton-Reilly, Wuensche, & Plimmer, 2017), intelligent conversational software agents (chatbot) (Schachner, Keller, & Wangenheim, 2020), virtual assistants (Jee, 2019), and online platforms for self-learning (Moreno, 2019). All these areas have a common goal: to learn, to teach and to solve problems (Baker, Smith, & Anissa, 2019).

Several studies have highlighted the different current trends in EAI (Roll & Wylie, 2016); thus, we can highlight the role of AI in special education (Guilherme, 2017), such as the transformative collaboration between teachers and students (Drigas & Ioannidou, 2013), the global advance and trends of various intelligent tutoring systems (Han, Zhao, Jiang, Oubibi, & Hu, 2019), the potential of EAI in higher education (Crompton, Bernacki, & Greene, 2020), etc. Hence, the importance to contribute to the improvement of academic performance by optimising instructional processes and reducing students' learning difficulties.

In our study, we understand academic performance as a measure of the student's abilities, which expresses what the student has learned throughout the learning process. It also implies the student's ability to respond to educational stimuli (Martínez, Karanik, Giovannini, & Pinto, 2015). Academic performance is affected by a multiplicity of heterogeneous factors (internal and external) that condition student performance, including aptitude and motivation (Castrillón, Sarache, & Herrera, 2020).

Research in the field of EAI and academic performance is a key area in education, since through its study the effectiveness of all these intelligent resources in the teaching and learning processes can be evaluated.

Considering all the above, this study aims to conduct an empirical analysis of the evidence found within the EAI literature. Despite previous systematic reviews on the inclusion of AI in education (Hooshyar, Yousefi, & Lim, 2019; Roll & Wylie, 2016; Song & Wang, 2020; Zawacki-Richter, Marín, Bond, & Gouverneur, 2019), the effect size on performance has not yet been calculated, quantified or meta-analysed. Thus, the main objective of the research is to analyse the impact of AI components and computational sciences on student performance. Focusing on EAI, this study attempts to address the following research questions:

- Does EAI improve student performance?
- What effects does EAI have on students?
- What type of AI and computational science is the most common in the educational field?
- Is EAI effective at all educational stages?

2 METHODS

2.1 Search Procedures

This study follows the guidelines of the PRISMA Statement (Page et al., 2021). The search was conducted on Web of Science (WOS) and Scopus databases, due to their prestige and scope in education research. For this purpose, the following search equation was introduced: SUBJECT: (AI-based education) OR SUBJECT: (artificial intelligence in education) AND SUBJECT: (e-learning) OR SUBJECT: (automated tutor) OR SUBJECT: (intelligence agent) OR SUBJECT: (simulation) OR SUBJECT: (artificial agent) AND SUBJECT: (student) AND SUBJECT: (experimental design) OR SUBJECT: (quasi-experimental design). The following inclusion criteria were adopted: (a) only articles, excluding the so-called grey literature; (b) whose language was English, as it is the internationally recognised language in the scientific field; (c) published between 2010 and 2020. In the search process, the volatility of educational technology was assumed, so it was decided to focus on empirical research published in the last 10 years; (d) belonged to the area of "Education Educational research or Education Scientific disciplines" in the case of WOS, and the research areas "social sciences, art and humanities, psychology and neuroscience" in Scopus. From the application of the initial inclusion criteria, the search was set at 480 manuscripts: 455 WOS and 25 in Scopus. There were 87 duplicates, so the initial sample was set at 393.

A first screening of the papers, resulting from the initial search, was conducted by examining the titles and abstracts. This phase was carried out by two of the authors. Unpublished dissertations, reviews and meta-analyses were excluded at this stage. This first screening resulted in a total of 41 articles that were fully read independently by the authors to verify whether the inclusion criteria were met. Of the 41 articles, only 18 fully achieved the inclusion criteria. A top-down search of articles citing or cited by those two articles was then performed to identify possible additional studies. This allowed the inclusion of five new articles. Finally, we looked for previous systematic reviews on AI, or some of its components, and analysed all the papers cited in those reviews for possible inclusion, considering two more studies in this last search. Thus, the final sample of articles reviewed for inclusion in this study was 25 articles. Figure 1 summarises the search process in a PRISMA flowchart.

2.2 Selection Criteria

The studies analysed must meet the following criteria to be included in this review: (a) the objective of the study was to measure quantitatively the impact of EAI, or one of its components, on the academic development of students; (b) the studies had to follow a pre-post design with control groups; (c) the dependent variable had to be related to academic performance; (d) the sample had to be made up of students.

2.3 Data Extraction and Coding

The review process of the manuscripts to reach the sample was carried out independently by two of the authors who signed the article. For this purpose, the data from the articles

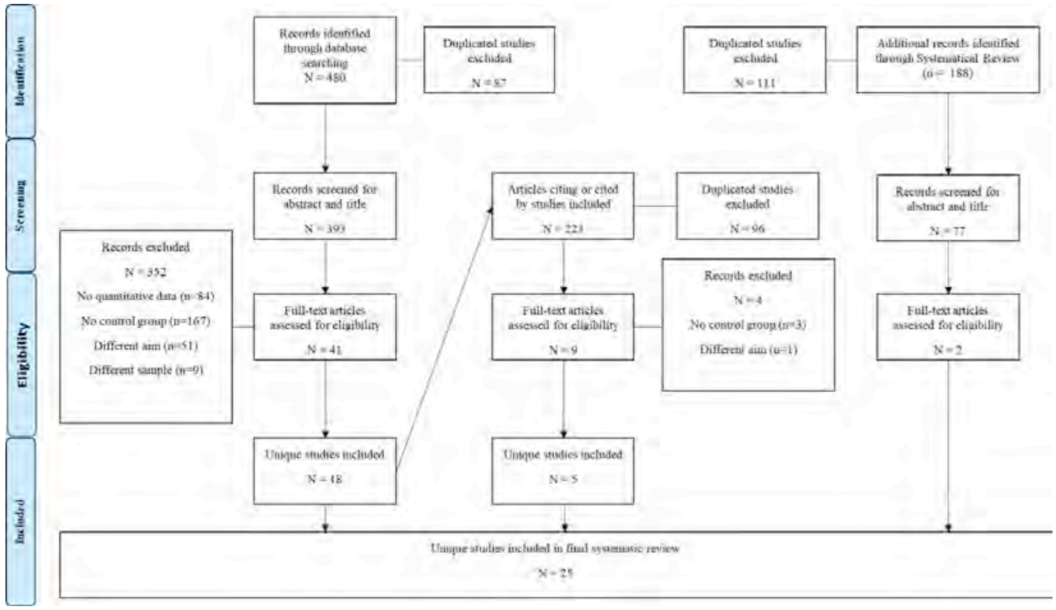

Figure 1 Sample selection flowchart

were analysed in an Excel file, according to the parameters provided by the inclusion and exclusion criteria, where a cell was added in order to determine whether or not they were included in the review and the reason for them. After completing each phase of the review (reading the title and abstract and the full text), the results obtained were contrasted.

The methodological quality of the selected articles was also assessed using Joanna Briggs' checklist (JBI), where it was examined by means of critical and independent review (eleven-point checklist) (Aromataris & Munn, 2020). For the internal assessment of the quality of the proposed study, the checklist was evaluated blindly by two researchers external to the research, with the aim of avoiding assessment bias by the authors themselves.

For the first complete reading made by the authors in the first search, the degree of agreement of inclusion of the papers was 96%. Disagreements were resolved by discussion and consensus between the two researchers until there was a 100% agreement. In the second search, the degree of agreement was 100%. The studies included were finally analysed in depth by the authors. All the relevant information of each article has been coded for the analysis and discussion procedure using a database, whose information has been interpolated into the figures and tables. Table 1 shows a summary of the detailed analysis of the 25 articles included in the systematic review.

Table 1 Articles included

Autors and Year	Journal	Country	N	Stage	Type of interventor	Intervention duration	DV	Tests used to measure DV	Results	Type of IA
J. L. Anderson and Barnett (2013)	Journal of Science Education and Technology	USA	91 CG = 32 EG = 59		Supercharged!	7 class periods	SA	CT	EG has better SA.	Ap
Barbalios, Ioannidou, Tzionas, and Paraskeuopoulos (2013)	Computer & Education	Greece	24		3D virtual reality modelling language	-	SA	CT	EG has better SA.	VR
Ibáñez, Serio, Villarán, and Kloos (2014)	Computer & Education	Spain	64		AR-based methodology vs. Web-based methodology	5 sessions	SA; P	CT	The AR-based application was more effective than the web-based application.	AR
Bortnik, Stozhko, Pervukhina, Tchernysheva, and Belysheva (1968)	Research in Learning Technology	Russia	50 CG = 25 EG = 25	U	Virtual chemistry lab combined with classroom vs. Traditional teaching	-	SA	R of EG and CG; CT; SP	EG has better SA.	Sim
Chin et al. (2010)	Educational Technology Research and Development	USA	Include 2 studies: 1) EG = 28 CG = 30 2) n = 104		Teachable agents application	1) 3 weeks 2) 15 weeks	SA	CT	EG has better SA.	Ap
Civelek, Ucar, Ustunel, and Aydın (2014)	Eurasia Journal of Mathematics Science and Technology Education	Turkey	EG = 106 CG =109		Immersive virtual reality environment (VRE)	2 weeks	SA; A	CT	EG has better SA.	VR
Yelamarthi and Drake (2014)	IEEE Transactions on Education	USA	EG = 17 CG = 24	U	Flipped course	Twice a week for 75 min over the 16 weeks	SA	CT	Significant improvements in EG students' performance and their perceptions of their learning experience.	Sim

Continued on next page

Table 1 continued

Autors and Year	Journal	Country	N	Stage	Type of interventor	Intervention duration	DV	Tests used to measure DV	Results	Type of IA
Olde, De Jong, and Gijlers (2013)	Educational Technology & Society	Netherla	EG = 21 CG = 28	TVS	Look-experiment-design (LED) by computer simulation	3 two-hour sessions	SA	CT	EG has better SA.	Sim
Dickerson and Clark (2018)	Computer Applications in Engineering Education	USA	CG = 31 EG = 22	U	SPICE simulation	12 weeks	SA	I, CT	EG has better and deeper SA.	Sim
Fang and Guo (2016)	Journal of Computer Assisted Learning		142 G = 65 EG = 77	U	Computer simulation and animation (CSA)	12 months	SA	CT	Better results with CSA, although they point out that the teacher's role cannot be replaced.	Ap
Fidan and Tuncel (2019)	Computer & Education	Turkey	EG1 = 30 EG2 = 31 CG = 30		AR based PBL with FenAR software	11 weeks	SA; A	CT; AS	The experimental results indicated that the integration of AR into the activities of PBL increased SA and AS.	AR
Jiménez, Bravo, and Bacca (2010)	Computer Applications in Engineering Education	Mexico	EG= 31 CG= 31	U	Web-based gamified software	20 days	SA	CT; MQ	EG scored better on the content test and displayed higher motivation than CG.	BL

Continued on next page

Table 1 continued

Autors and Year	Journal	Country	N	Stage	Type of interventor	Intervention duration	DV	Tests used to measure DV	Results	Type of IA
Madathil et al. (2017)	Computers in Education Journal	USA	165	U	Instructional model with VR integrated	1 hour	SA, Sa, U; PE	CT	Although no significant learning differences were found between the conditions, students' perceptions of their learning showed significant improvements in the VR and control groups over the photo-based group. VR improves the learning experience.	VR
Neri, Noguez, Robledo-Rella, Escobar-Castillejos, and Gonzalez-Nucamendi (2018)	Journal of Educational Technology & Society	Mexico	EG = 47 CG = 38	U	Visuo-haptic simulators	5 months	SA	PQ, R, CT	Incorporating haptic technology in learning simulators to teach physics enhance the understanding of physics concepts motivation and SA.	Ap
Pellas and Vosinakis (2018)	Education and Information Technologies	Greece	50		Scratch and OpenSim with Scratch4SL	4-weeks period with 6 sessions	SA	CT	EG performed better on problem-solving measures and algorithmic thinking.	Sim
Stieff (2011)	Journal of Research in Science Teaching	USA	460		Connected Chemistry: Discovering Matter!	180 minutes with different distributions in each case: 4x45; 2x90...	RC; SA	CT	Connected Chemistry class yield only small to modest improvements in SA but higher RC.	Sim

Continued on next page

Table 1 continued

Autors and Year	Journal	Country	N	Stage	Type of interventor	Intervention duration	DV	Tests used to measure DV	Results	Type of IA
Zacharia and Olympiou (2011)	Learning and Instruction	Cyprus	234	U	Traditional vs. Physical manipulative experimentation vs. Virtual manipulative experimentation (VME)	2 semesters Duration: 30.5 hours	SA	CT	Better results in the experimental groups.	VR
J. Anderson and Barnett (2011)	Journal of Science Education and Technology	USA	CG = 65 EG = 71	U	Labs with and without Supercharged!	2 labs of 2 h each	SA	CT; LN	Video games can lead to positive learning outcomes and support student scientific understanding.	Ap
Bozkurt and Ilik (2010)	Procedia Social and Behavioral Sciences	Turkey	152	U	Computer simulations (E) vs. Traditional (C)	1 semester	SA; B	CT	Groups who study with computer simulations are more successful than those who study with traditional methods.	Sim
Pareto (2014)	International Artificial Intelligence in Education Society	Sweden	443	P	Teachable agents application	3 months	SA	CT	Teachable agents in educational games can help achieve deeper levels of learning and motivational power.	Ap

Continued on next page

Table 1 continued

Autors and Year	Journal	Country	N	Stage	Type of interventor	Intervention duration	DV	Tests used to measure DV	Results	Type of IA
Riess and Mischo (2010)	International Journal of Science Education	Germany	CG = 84 EG1 = 115 EG2 = 112 EG3 = 113	S	Four conditions: computer-simulated forest game only vs. Teaching unit on systems thinking vs. Combination of computer-simulated forest game and teaching unit on systems thinking vs. "Traditionally" lessons	26 lessons	SA	CT	Significant increase in systems thinking can only be seen in the experimental condition "simulation and lessons", whereas the other experimental conditions show either no increase or only a tendential one.	Sim
Shegog et al. (2012)	Research in Science Education	USA	44 treatment = 23; comparison = 21	S	Virtual lab	1 day	SA; ATS, ATS	CT, ATC, ATS;	EG increased their procedural and declarative knowledge, became more positive toward using computers for learning but did not affect attitudes toward science.	Sim
Tatli and Ayas (2013)	Journal of Educational Technology & Society	Turkey	90 CG =30 CG2 = 30 EG = 30	S	Quasi-experimental method	6 weeks	SA	CT; UO	Virtual laboratories are at least as effective as physical ones.	Ap
Veredas, Ruiz-Bandera, Villa-Estrada, Rufino-González, and Morente (2014)	Computer Methods and Programs in Biomedicine	Spain	EG= 30 CG= 42	U	ePULab tool	4 hours	SA	CT	Students using ePULab gave significantly better learning acquisition scores than those following traditional lecture-style classes.	AVT

Continued on next page

Table 1 continued

Autors and Year	Journal	Country	N	Stage	Type of interventor	Intervention duration	DV	Tests used to measure DV	Results	Type of IA
Walker, Rummel, and Koedinger (2014)	International Artificial Intelligence in Education Society	USA	130	S	Adaptive peer tutoring assistant (APTA)	130 minutes	SA	CT	Improved student achievement.	Ap

Note. DV: Dependent Variable; CG: Control Group; EG: Experimental Group; P: Primary Education; S: Secondary Education; U: University; TVS: Technical Vocational School; SA: Student Achievement; ATS: Attitude to Science; B: Beliefs; RC: Representation Competence; ATC: Attitudes Toward Computers for Learning; SP: Student Portfolios R: Reports; PQ: Perception Questionnaire; CT: Content Tests; I: Interviews; MQ: Motivation questionnaire; Sa: Satisfaction; U: Usability: PE: Perceived Engagement; LN: Laboratory Notebooks; UO: Unstructured Observations; VR: Virtual Reality; AR: Augmented Reality; Ap: Application; Sim: Simulations; BL: B-learning; AVT: Artificial Vision Techniques.

2.4 Computation of Effect Sizes and Statistical Analyses

To analyse quantitatively the impact of EAI-based interventions on academic achievement, the effects size of the results of each of the included studies was estimated. One of the inclusion criteria was that the studies employed a control group design and pre-post measures, so the standardized mean change difference score recommended by Morris (2008) was used to estimate effect size. However, although all studies met the design criteria, 11 of them did not provide information on the pre-test measure. For these studies, the effect size was estimated by means of the standardized mean difference of post-test scores, and a second analysis was carried out with them.

Standardized mean change difference scores (g_{Δ}) were calculated with equations 8-10 of Morris (2008); and the variance of the effects, with equation 25. For the analysis focused only on the post-test, the effect size (g) was computed using equations 4.18 and 4.19 of Borenstein, Hedges, Higgins, and Rothstein (2009), including the correction factor J, calculated with equations 4.22 and 4.23. As for the variance of gp, equations 4.20 and 4.24 of Borenstein et al. (2009) were used. Since some of the included studies offered more than one dependent variable to analyze the statistical dependence of the effect sizes within the same study, the analysis with a multi-level random-effects model using the rma.mv function of the metafor package for R was adjusted (Viechtbauer, 2010).

3 RESULTS

3.1 Characterization of the Studies Examined

The studies in this systematic review share the objective related to assess the impact of AI-based models and computational sciences on student achievement. The wide range of research about AI and computational sciences has led to the inclusion of empirical research on different types developed at different educational stages around the world (see Table 1).

Among the studies conducted in primary education, the research of Chin et al. (2010), Barbalios et al. (2013) and Pareto (2014) should be mentioned. The first one addresses teachable agents with K-12 students, and its purpose was to facilitate student learning through concept mapping with an AI tool. Their findings reported that the use of this tool promotes the consolidation and acquisition of future learning in the area of science. On the other hand, the study of Barbalios et al. (2013) also took place in the above-mentioned area, specifically in environmental education. Its design consisted of using a realistic virtual environment with 3D technology where water simulations are developed in order to help students to achieve cognitive advances on ecosystems and acquire complex abstract notions with respect to other groups where other types of instruction were used. Unlike previous studies, the study conducted by Pareto (2014) focused on the area of mathematics with students from second to sixth grade. Using the game as the core on which the whole study is based, this research encourages an approach to discover knowledge in a playful way, providing the possibility of incorporating the teachable agents as an extension of the game in which students are guided and orientated so that they acquire learning through a set of questions, while giving them the possibility of reflecting on mathematical learning.

Advancing from the educational stage, the studies of J. Anderson and Barnett (2011); Civelek et al. (2014); Fidan and Tuncel (2019); Ibáñez et al. (2014); Pellas and Vosinakis (2018); Riess and Mischo (2010); Shegog et al. (2012); Stieff (2011); Tatli and Ayas (2013) and Walker et al. (2014) were carried out in secondary education; and Olde et al. (2013), in vocational education. Regarding the first one, the study by) J. L. Anderson and Barnett (2013) used the Supercharged! application, based on the video game to teach complex concepts about electromagnetism. Among their main findings, they highlight the effectiveness of using such applications for the consolidation of complex concepts and the development of higher order metacognitive skills. Also related to the teaching of electromagnetism notions is the research of Ibáñez et al. (2014), which uses AR and whose findings were similar. In turn, in the area of physics and the use of simulations to achieve better academic results among students, the research by Civelek et al. (2014) with K-12 students should be emphasised. The contribution of this work, compared to others, is the measurement of student achievement, together with the attitude of students towards physics. In this regard, not only do simulations and, therefore, the AI, favour student learning, but there is also a change in student attitude towards STEM (Science, Technology, Engineering, and Mathematics) matters. In this line, it is also worth mentioning the study of Shegog et al. (2012) in the area of biology for the learning of transgenic animal models through simulations, finding that their use, apart from allowing access to certain concepts which otherwise would not be possible, reported improvements in achievement among students and advances in the students' attitude towards the study of biology. In addition, the study carried out by Fidan and Tuncel (2019), which links AR to problem-based learning, explores the effect of these strategies on student achievement and their attitude towards physics, while providing teachers with some keys for incorporating these strategies into the instructional processes. Also contextualised in problem solving, but in this case, using simulation games, is the study conducted by Pellas and Vosinakis (2018). The research was implemented in a programming course with K-12 students, where it was determined that the use of OpenSim with Scratch4SL led to the development and improvement of computational strategies and more correct codes in problem solving. Within the contextualised studies in science, stands out the research of Stieff (2011), who used the simulations to facilitate the understanding of both molecules and representational skills in the area of chemistry. Specifically, the implementation of Connected Chemistry revealed better results in achievement compared to other modes of instruction, although the curriculum and the teacher were positioned as other decisive factors when interpreting these findings. In contrast, students in Connected Chemistry showed a tendency to use representations in the post-test. Developed in a virtual chemistry laboratory environment, the study by Tatli and Ayas (2013) found a similar effectiveness between the virtual laboratory and the real laboratory in terms of achievement. In the area of biology, through simulations for sustainable education, the research by Riess and Mischo (2010) revealed quantitative improvements in student achievement in the computer simulation condition, as well as in the combination of computer simulation and lesson condition with respect to the control group. As for vocational education, the study of Walker et al. (2014), aimed at analysing the effects of intelligent peer tutoring on the quality of students' collaborative and perceived support interactions and the effects they report on their learning, suggests a significative improvement regarding other non-adaptive modalities.

In Higher Education, there are studies such as Bortnik et al. (1968), which demonstrated the positive effects of implementing an "adopted approach" combining both virtual and practical learning environments. This had the potential to improve students' research skills and practice in analytical chemistry studies. In this vein, Yelamarthi and Drake (2014) analysed the effect of introducing simulations in Digital Circuits Course with engineering students and found that students improved their performance and their interest towards learning thanks to the combination of active strategies and online preview of lectures, face-to-face student/instructor and peer interactions, discussions and hands-on activities. The study carried out by Jiménez-Hernández, Oktaba, Díaz-Barriga, and Piattini (2020) implemented an experiment to prove the effectiveness of web-based gamified software in the use of Booleans in a b-learning situation, with improvements in both performance and motivation in the experimental group.

Studies based on AI are also being developed in the field of medical education. For example, the study conducted by Veredas et al. (2014) compared the performance of students in the ePULab modality versus the traditional one and found better academic results in the experimental group.

For their part, Dickerson and Clark (2018) used the simulation tool SPICE in a microelectronics course, finding improved performance and positive disposition towards active learning. Similarly, the study conducted by Neri et al. (2018) within a mechanics course involving visuo-haptic simulators reported better results in both achievement and motivation compared to the control groups. Using the potential of simulations in education, the study made by Fang and Guo (2016) contextualised in an undergraduate engineering dynamics course informed improved outcomes in terms of conceptual and procedural learning. Using AR, the research undertaken by Madathil et al. (2017) analysed the achievement, perceived commitment, user-friendliness and satisfaction of 165 university students enrolled in technical careers. They designed 2 experimental conditions: one based on VR; and the other, on a case study with photos and one control group. The experimental group performed better in terms of achievement than the other two groups and obtained higher scores in terms of commitment, ease of use and satisfaction than the other experimental group, although it matched the control group. The research by Zacharia and Olympiou (2011) confirmed the importance of physical and virtual manipulation in learning acquisition.

In this regard, J. Anderson and Barnett (2011), who used video games to teach the principles of electromagnetism to future teachers with Supercharged!, found different results to those obtained by the authors in secondary schools (J. L. Anderson & Barnett, 2013). In this case, even though the future teachers in the experimental group performed the tasks better, their scores were lower than those of the control group.

Finally, Bozkurt and Ilik (2010) found that computer simulations improved both student achievement and their attitude towards physics education.

3.2 Qualitative Meta-analysis

Figure 2 shows the distribution of effects of the included studies using a forest plot for the pre-post meta-analysis (panel A) and for the post meta-analysis (panel B). Of the 25 studies that were included in the analysis, 11 provided information to estimate the effect size for the pre-post meta-analysis. The average effect was g_{Δ} = 0.552, 95% CI [-0.046, 1.150], not being statistically significant; z = 1.809, p = .070. The level of heterogeneity was significant: Q (39) = 785.498, p < .001. Regarding the standardized mean change difference scores for post-test meta-analysis, the mean effect was significant: gp = 0.716, 95% CI [0.426, 1.007], z = 4.833, p < .001. And the effect distribution revealed significant heterogeneity: Q (53) = 685.060, p < .001.

Figure 3 represents the distribution of estimated effect sizes for the studies included in $g\Delta$ (panel A) and the studies included in gp (panel B) using a funnel plot. As can be seen in the figure, both distributions show a high asymmetry in the distribution of effects. The red line represents Egger's regression test. This test analyses the asymmetry that shows the distribution of the effects for each analysis. Both regressions showed to be significant: b1 = 15.662, z = 11.395, p < .001 in the case of $g\Delta$, and b1 = 18.397, z = 14.483, p < .001 for gp.

Finally, the moderating role that AI types could indicate on the total effect was analysed. Table 2 summarises the results of the moderator analysis for $g\Delta$ and gp. As it can be seen in the Q-test results, the AI type did not show a significant difference on the effect size for the analysis of $g\Delta$; on the contrary, it exhibited a significant effect size for the analysis of gp. Numerically, the type of AI VR tends to present an effect size ($g\Delta$ = 2.01 and gp = 1.28) on its impact on learning that is higher than the other types of AI manipulation. The Application type also reveal to be a manipulation associated with an acceptable effect size ($g\Delta$ = 0.39 and gp = 0.92), showing a significant effect in gp analysis.

Table 2 Moderator analysis for effect size

Analysis	Moderator	*g*	LL	UL	*z*	*p*	*k*	Q	*df*	*p*
gΔ	Type of AI							5.29	4	.25
	Apli	0.39	-0.63	1.42	0.75	.450	8			
	VR	2.01	-0.01	4.04	1.94	.051	20			
	Sim	0.47	-0.55	1.49	0.90	.368	9			
	AR	0.25	-1.21	1.73	0.34	.731	3			
g	Type of AI							36.86	4	<.001
	Ap	0.92	0.48	1.36	4.09	<.001	12			
	VR	1.28	0.61	1.94	3.77	<.001	25			
	Sim	0.49	0.08	0.90	2.35	.018	14			
	AR	0.20	-0.52	0.93	0.54	.582	3			

Note. VR: Virtual Reality; AR: AugmentedReality; Ap: Application; Sim: Simulations; g= effect size; LL = lower limit of the 95% CI; UL = upper limit of the 95% CI; z = z-scoreassociated with the g value in thesame row; p = p-value associated with the z-scorein the same row; k = number of effectsizes contributing to g in the samerow; Q = result of the Q-test for moderation; df = degrees of freedom of the Q-test for moderation; p = p-valueof the Q-test for moderation.

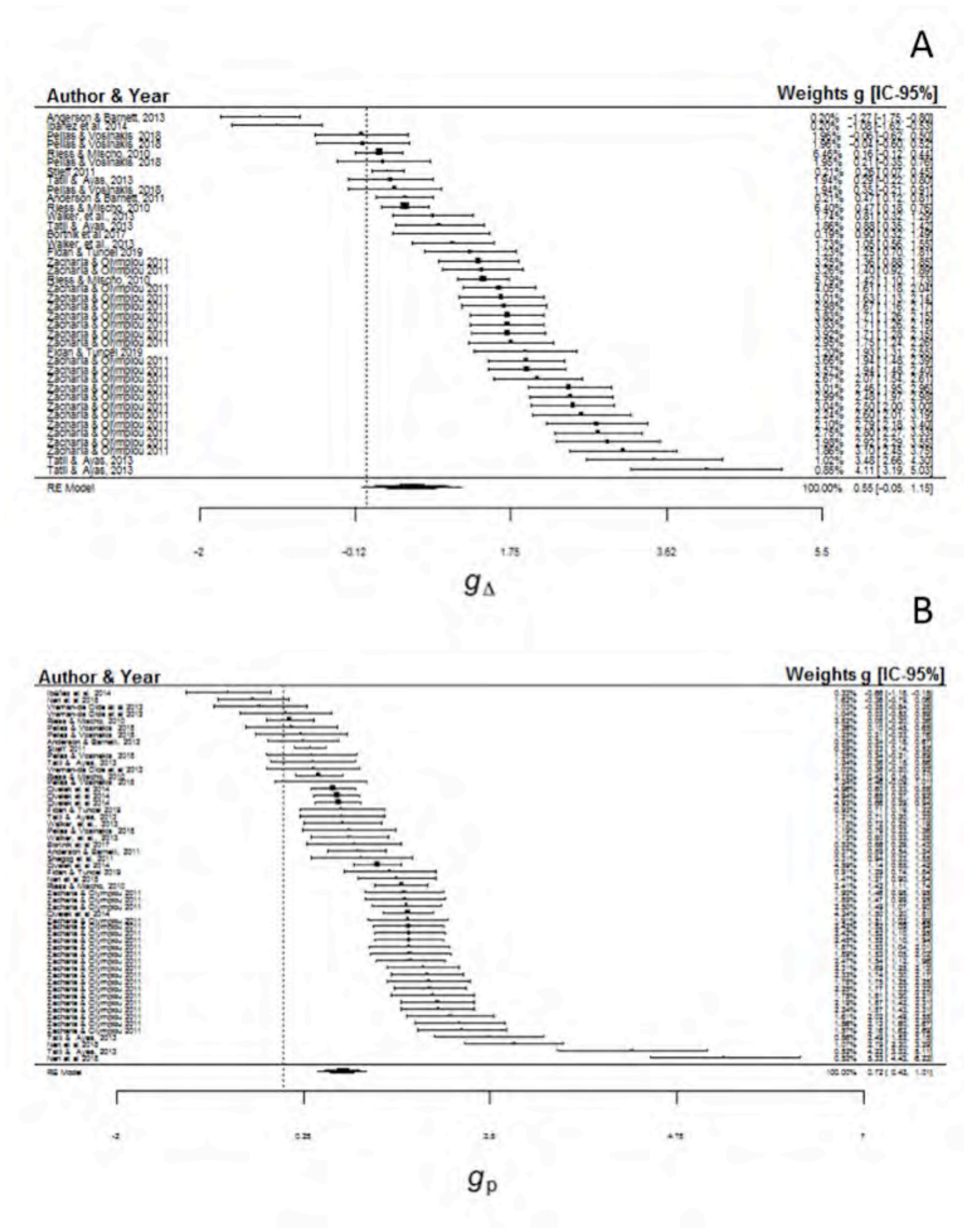

Figure 2 Forest plot for g∆ (panel A) and gp(panel B)

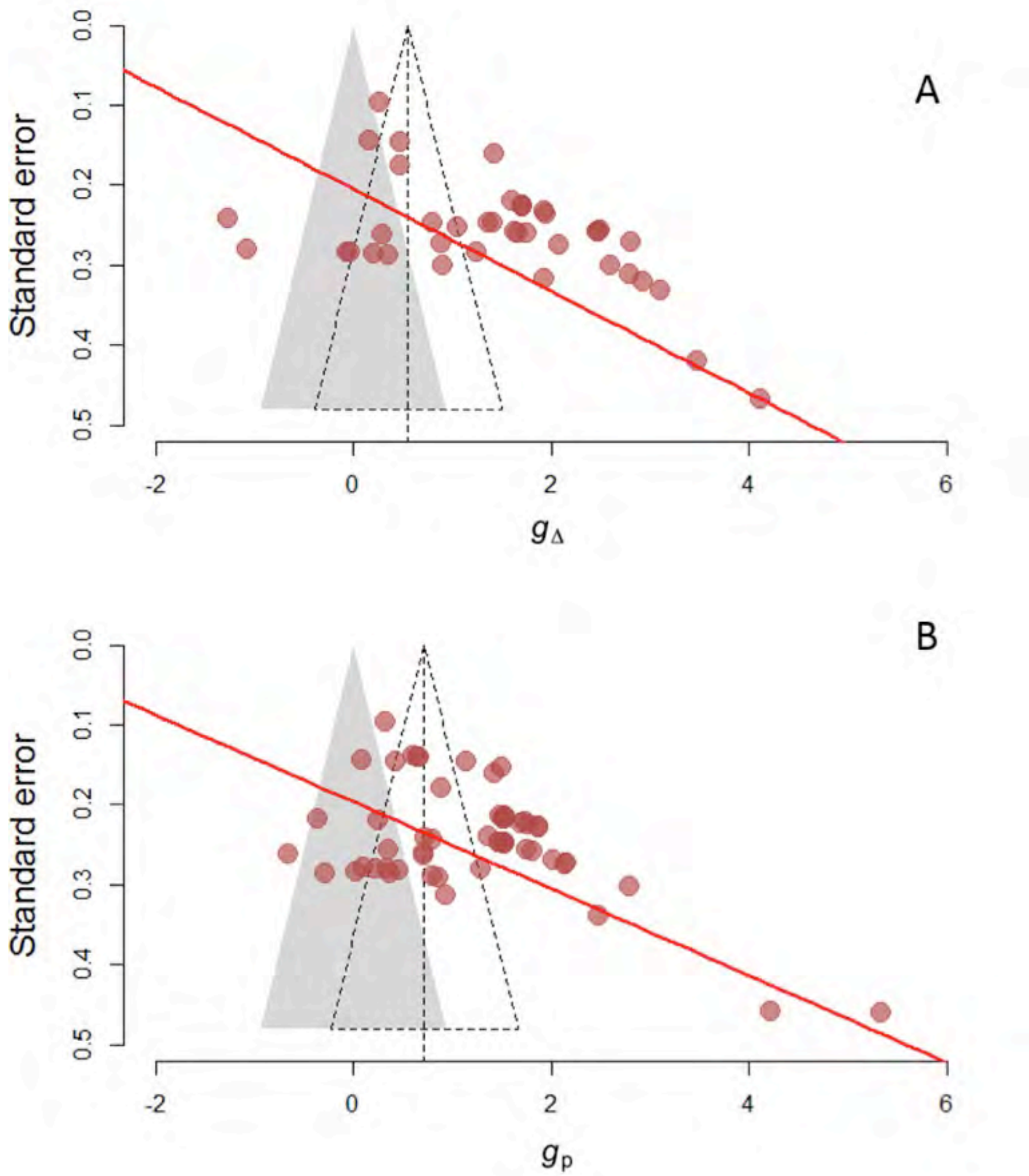

Figure 3 Funnel plots for g∆ (panel A) and gp(panel B)

4 DISCUSSION AND CONCLUSIONS

The systematic review carried out aimed at analysing the impact of different AI components and computational sciences on student performance. After applying the inclusion and exclusion criteria mentioned above, the search resulted in 25 quasi-experimental studies with experimental and control groups, and/or hybrids, incorporating, in addition, qualitative strategies, which examined the positive effects of applying AI and computational sciences with respect to traditional methods.

Specifically, it was intended to provide answers to four research questions, which will be answered below:

4.1 Does EAI Improve Student Performance?

All the studies found have shown the usefulness of employing EAI-based methods over more traditional methods. Among the pedagogical intentions and considerations that justify the use of EAI-based methods, the importance of placing students into the heart of their learning, providing them with opportunities to take an active role in that construction, stands out. The pedagogical possibilities offered by EAI are oriented to achieve significant learning in students, encouraging the visual component that has its different modalities, such as simulations, VR, AR, or applications such as games.

One of the great benefits of EAI is the flexibility to adapt educational programs to the rhythms and circumstances of each student (Deng, Benckendorff, & Gannaway, 2019; Vilkova & Shcheglova, 2020). Considering the advances in society and technology, teaching and guidance by teachers may often be done in a non-face-to-face modality. These modalities are the basis of distance education. This type of education arises due to the incompatibility between individuals' studies and their work, or to situations of major importance, such as the global pandemic we are experiencing. Moreover, one of the main advantages of using technology in distance education is video tutorials (Wilkie & Liefeith, 2020). Students obtain personalised feedback on their teaching-learning process through them. On the other hand, teachers can record their classes or brief extracts of any content and students can watch it as often as necessary for their proper learning (Elliot, Gehret, Valadez, Carpenter, & Bryant, 2020; López-Rodríguez & Barac, 2019).

4.2 What Effects Does EAI Have on Students?

Based on our research findings, we have identified that the different EAI modalities not only affect the quantity of what students learn, but also lead to higher levels of motivation, which is demonstrated by a greater willingness to be involved in their learning. At the same time, it has been shown that most studies on EAI have been contextualised in STEM knowledge areas, which require higher levels of abstraction and greater complexity to achieve a proper understanding of knowledge. Depending on the level of education, different resources can be used so that the students are encouraged to manipulate them. In this regard, EAI not only helps to keep students focused while they are building something, but also encourages their creative ability to shape their thoughts (Barak & Zadok, 2009). Likewise, several studies use and have demonstrated the effectiveness of the AI tools in education (Fabregas et al., 2016; Jiménez et al., 2010). In addition, many educational institutions around the world are employing the STEM teaching methodology. This methodology is characterised using a series of new and up-to-date tools for the teaching of different school subjects. Moreover, it allows the design and development of a computational model based on learning and teaching conditions controlled on any subject with a high visual and multimedia content, which facilitates the acquisition and understanding of the contents through the ongoing interaction with the computer (Vlachopoulos & Makri, 2017).

In some of the studies included, besides checking the effectiveness of EAI on the quantity and quality of student learning, it has been shown how these modalities have led to changes in students' attitudes towards these knowledge areas. In this regard, it may be determined that incorporating technologies, resources and EAI strategies into teaching methodologies is a significant advance on the road to achieving a meaningful and integrated student learning.

4.3 What Type of AI and Computational Science is the Most Common in the Educational Field?

Regarding the type of AI modality used, it was found that the different studies included address the potential of EAI on student performance through applications (n = 8), simulations (n = 8), VR (n = 4) and AR (n = 2). In relation to the applications, the literature suggests that their use in education is increasingly widespread at all levels (Wirjawan et al., 2020). Given their high impact on students, subject-based learning is contextualised and updated to the digital society. Applications are contextualised to the subject matter and educational level of the student. There are applications that allow the user to interact with their environment, use question and answers, find some element, orientate, watch instructional videos, create a portfolio, learn mathematics, play video games, and even intelligent tutoring. Likewise, research can be found that focuses on the use of some application carried out at any educational stage (Dunleavy et al., 2019; Hoplock, Lobchuk, & Lemoine, 2020; Petko et al., 2019). It is also important to note that apps tend to be used more frequently by teachers, due to their greater accessibility compared to other AI modalities, such as Big Data, which requires a higher level of literacy and involve other variables such as ethical issues (Gao, Li, & Liu, 2021). We can also find how there are studies in which different applications are used with people with autism (Law, Dutt, & Neihart, 2019) or in people with attention deficit hyperactivity disorder (Butt et al., 2020; Păsărelu, Andersson, & Dobrean, 2020). This implies that this type of AI is easier to implement in the design, adjustment and development of instructional processes for learners with special educational needs (Zhai et al., 2010).

Regarding the simulations, they provide a variety of scenarios in which students can learn by discovering applying what they have learned to progress at different levels, playing games or solving day-to-day problems (Masson & Rennie, 2006). Their easy access, potential for individualisation and low cost are some of the benefits that encourage its widespread use in education (Cabero-Almenara & Costas, 2016).

Among the findings obtained in these studies, there are common results and objectives: many of them sought to understand complex concepts in subjects classified as "difficult" and to strengthen and improve the students' attitude towards the subject and, in some cases, to establish collaborative strategies among students. Likewise, the research that used the simulations as an AI, AR and VR modality was oriented to offer more real learning situations for the students, demonstrating an effectiveness similar to that of real laboratories. These experiences allow students to interact with an outside environment within the classroom (Lau & Lee, 2015). Furthermore, the use of VR in education enables students to interpret signs, whether visual, auditory, or haptic, and to build their knowledge through their movement and their interaction with their own environment (Beck, 2019; Vesisenaho et al., 2019). In order to implement this technology into practice at school, teachers need to experiment with it, learn how to use it and then contextualise the content to the students' own environment Tondeur, Roblin, Van Braak, Voogt, and Prestridge (2017). In higher education, university studies in medicine or nursing include the use of VR to perform operations or treatments (Baxter & Hainey, 2019; Bernardo, 2017).

4.4 Is EAI Effective at All Educational Stages?

The systematic review and meta-analysis have included studies from different educational stages. Thus, there are three studies in primary education, eleven contextualised studies in secondary education, one in vocational studies and ten studies in university. In all of them, the effectiveness of AI has been shown. However, the superiority of research in secondary education and university seems to point to a tendency to develop more studies in advanced educational stages, due, among other reasons, to the potential intellectual growth of students at these stages.

Similarly, small differences in terms of the type of AI and computational science have been observed in the different educational stages. According to the results obtained, there is a more restricted trend towards the use of AI and computer science, with applications and simulations becoming the most widely used in primary education. On the other hand, in secondary education and university, there is a tendency to use more types of AI and computational science, also due to the wide variety of subjects that can be studied and the tendency to encourage more computational thinking in students than in previous educational stages. However, this differs from Sun, Guo, and Hu (2021), who state that the use of gamification strategies to enhance computational thinking tends to be more effective at lower educational stages, making gamification a factor to be considered in this analysis.

4.5 Strengths and Limitations of the Study

In this regard, there is a change of trend in relation to the development of studies that use AI and promote computational thinking in students due to the pressure from international organisations to include computational thinking in the curricula at all educational stages. Thus, an increasing number of research studies is being found in the literature that uses AI and promotes computational thinking at different educational stages (McCormick & Hall, 2022; Merino-Armero, González-Calero, & Cozar-Gutierrez, 2022). This paper has a set of limitations that need to be emphasized. Firstly, the limitation related to the lack of studies that empirically demonstrate the relationship between AI and student achievement was considered. Another issue to take into account is determined by the databases themselves. Problems are often perceived in the registration of manuscripts, depending on the type of document or language, which may imply any possible bias in the elaboration of the systematic review. Related to this, the choice to use exclusively the WOS and Scopus databases and to ignore other publication sources, such as ERIC, PSYINFO, or the grey literature, may lead to bias. However, it was considered appropriate to focus on them because of its prestige and since they are the databases that include the most manuscripts in the research area. In addition, this paper also has several strengths that should be noted. For example, this review has quantitatively assessed the effect of different EAI-based studies on student performance. In addition, studies from different countries have been collected, which provides an overview of this topic.

4.6 Contribution of This Paper

Experiences of AI in education can be found in the literature. Most of the works highlight the potential of AI to facilitate the understanding of complex and abstract knowledge. However, the negative points emphasize that AI requires specific software and the design of materials and technological resources. This particular paper provides scientific evidence of the real benefits of incorporating AI into educational processes, based on the meta-analysis conducted. Specifically, the size of the effect of the different AI modalities and computational sciences on the academic performance of students has been measured, and the benefits have been found to be real. Despite the high economic cost, this work gathers experiences of AI in different educational stages, which opens the way towards the implementation of teaching methodologies based on AI in both early childhood and higher education, with a view to decreasing learning difficulties in students and increasing their motivation towards learning. Similarly, it is important to note the impact on teachers themselves. While it is true that the use of AI and computer science in the field of education can provide significant support for teachers, who have seen their roles increase over the last few years. However, it also brings with it several challenges that need to be clarified. Firstly, there is digital literacy, where they must know how these modalities work, their viability and usefulness in their subject, as well as how to extrapolate it to the reality of their classroom in order to build meaningful learning situations for their students. Secondly, it must consider the sustainable objectives proposed by UNESCO (2021) both in the design of learning situations and in their implementation, in order to ensure that ethical assumptions are met and that human potential is enhanced rather than hindered (Flores-Vivar & García-Peñalvo, 2023; UNESCO, 2019). Accordingly, challenges that teachers must take on

Table 3 Challenges for teachers for the inclusion of EAI. Adaptation of Flores-Vivar & García-Peñalvo (2023; pp. 4-5).

Dimensions and proposals	Challenges	Educational stage
Accessibility	Design and use of new educational resources.	All educational stages
Intelligent tutoring	Monitoring of intelligent system-generated responses to ensure that the ethical guidelines of SDG 4 are met.	University
Virtual facilitators	Design of new pedagogical models that include AI and computer science.	All educational stages
Intelligent content	Ethical and legal issues related to intellectual property.	Secondary Education and University
Teacher and AI collaboration	Digital literacy plans.	All educational stages
Content management and analytics	Ethical issues associated with data processing.	University
Out-of-class tutoring	Human-machine interaction paradigm.	Secondary Education and University
Learning management automation	Resource optimization.	All educational stages

in the inclusion of AI in the field of education have been identified (see Table 3).

4.7 Recommendations for Further Research

Based on the findings and limitations identified, the study should be extended to other databases, such as ERIC or PsycINFO, or the grey literature, which provide a worldwide view of current research on AI and students performance. During the search for studies carried out, it has been observed that the problem has grown exponentially over time.

5 AUTHORS' CONTRIBUTION

Conceptualization: Inmaculada García-Martínez and José María Fernández-Batanero; **Data curation:** Samuel P. León; **Formal analysis:** Samuel P. León; **Funding acquisition:** José María Fernández-Batanero; **Investigation:** Inmaculada García-Martínez and José Fernández-Cerero; **Methodology:** Inmaculada García-Martínez and Samuel P. León; **Software:** Samuel P. León; **Writing – original draft:** Inmaculada García-Martínez, José Fernández-Cerero and Samuel P. León; **Writing – review & editing:** Inmaculada García-Martínez and José María Fernández-Batanero; **Supervision:** All authors have reviewed and approved this manuscript.

ACKNOWLEDGEMENTS

Funded by: Spanish State Research Agency, Spain
Funder Identifier: http://dx.doi.org/10.13039/501100011033
Award: PID2019-108230RB-I00

REFERENCES

Anderson, J., & Barnett, M. (2011). Using video games to support pre-service elementary teachers learning of basic physics principles. *Journal of Science Education and Technology*, *20*(4), 347–362. https://doi.org/10.1007/s10956-010-9257-0

Anderson, J. L., & Barnett, M. (2013). Learning physics with digital game simulations in middle school science. *Journal of Science Education and Technology*, *22*(6), 914–926. https://doi.org/10.1007/s10956-013-9438-8

Aromataris, E., & Munn, Z. (2020). Chapter 1: JBI Systematic Reviews. *JBI manual for evidence synthesis*. Joanna Briggs Institute: Joanna Briggs Institute. Retrieved from https://doi.org/10.46658/JBIMES-20-02 https://doi.org/10.46658/JBIMES-20-02

Baker, T., Smith, L., & Anissa, N. (2019). *Educ-AI-tion rebooted? Exploring the future of artificial intelligence in schools and colleges*. Retrieved from https://media.nesta.org.uk/documents/Future_of_AI_and_education_v5_WEB.pdf

Barak, M., & Zadok, Y. (2009). Robotics projects and learning concepts in science, technology and problem solving. *International Journal of Technology and Design Education*, *19*(3), 289–307. https://doi.org/10.1007/s10798-007-9043-3

Barbalios, N., Ioannidou, I., Tzionas, P., & Paraskeuopoulos, S. (2013). A model supported interactive virtual environment for natural resource sharing in environmental education. *Computers*

& Education, *62*, 231–248. https://doi.org/10.1016/j.compedu.2012.10.029

Baxter, G., & Hainey, T. (2019). Student perceptions of virtual reality use in higher education. *Journal of Applied Research in Higher Education*, *12*(3), 413–424. https://doi.org/10.1108/jarhe-06-2018-0106

Beck, D. (2019). Augmented and Virtual Reality in Education: Immersive Learning Research. *Journal of Educational Computing Research*, *57*(7), 1619–1625. https://doi.org/10.1177/0735633119854035

Bernardo, A. (2017). Virtual reality and simulation in neurosurgical training. *World Neurosurgery*, *106*, 1015–1029. https://doi.org/10.1016/j.wneu.2017.06.140

Borenstein, M., Hedges, L. V., Higgins, J., & Rothstein, H. R. (2009). When does it make sense to perform a meta-analysis. *Introduction to Meta-Analysis*, 357–364. https://doi.org/10.1002/9780470743386.ch2

Bortnik, B., Stozhko, N., Pervukhina, I., Tchernysheva, A., & Belysheva, G. (1968). Effect of virtual analytical chemistry laboratory on enhancing student research skills and practices. *Research in Learning Technology*, *25*, 1968. http://doi.org/10.25304/rlt.v25.1968

Bower, M., Dewitt, D., & Lai, J. W. (2020). Reasons associated with preservice teachers' intention to use immersive virtual reality in education. *British Journal of Educational Technology*, 1–19. https://doi.org/10.1111/bjet.13009

Bozkurt, E., & Ilik, A. (2010). The effect of computer simulations over students' beliefs on physics and physics success. *Procedia-Social and Behavioral Sciences*, *2*(2), 4587–4591. https://doi.org/10.1016/j.sbspro.2010.03.735

Butt, S., Hannan, F. E., Rafiq, M., Hussain, I., Faisal, C. N., & Younas, W. (2020). Say-It & Learn: Interactive Application for Children with ADHD. *International Conference on Human-Computer Interaction* (pp. 213–223). Springer. https://doi.org/10.1007/978-3-030-49913-6_18

Cabero-Almenara, J., & Costas, J. (2016). Simulators use for students training. *Prisma Social*, *7*, 343–372.

Castrillón, O., Sarache, & Herrera, R. (2020). Predicción del rendimiento académico por medio de técnicas de inteligencia artificial. *Formación Universitaria*, *13*(1), 93–102. http://doi.org/10.4067/S0718-50062020000100093

Chin, D. B., Dohmen, I. M., Cheng, B. H., Oppezzo, M. A., Chase, C. C., & Schwartz, D. L. (2010). Preparing students for future learning with teachable agents. *Educational Technology Research and Development*, *58*(6), 649–669. https://doi.org/10.1007/s11423-010-9154-5

Civelek, T., Ucar, E., Ustunel, H., & Aydın, M. K. (2014). Effects of a haptic augmented simulation on K-12 students' achievement and their attitudes towards physics. *Science and Technology Education*, *10*(6), 565–574. https://doi.org/10.12973/eurasia.2014.1122a

Crompton, H., Bernacki, M., & Greene, J. A. (2020). Psychological foundations of emerging technologies for teaching and learning in higher education. *Current Opinion in Psychology*, *36*, 101–105. https://doi.org/10.1016/j.copsyc.2020.04.011

Deng, R., Benckendorff, P., & Gannaway, D. (2019). Progress and new directions for teaching and learning in MOOCs. *Computers & Education*, *129*, 48–60. https://doi.org/10.1016/j.compedu.2018.10.019

Dickerson, S. J., & Clark, R. M. (2018). A classroom-based simulation-centric approach to microelectronics education. *Computer Applications in Engineering Education*, *26*(4), 768–781. https://doi.org/10.1002/cae.21918

Drigas, A. S., & Ioannidou, R. E. (2013). A review on artificial intelligence in special education. *Communications in Computer and Information Science*, 385–391. https://doi.org/10.1007/978-3-642-35879-1_46

Dunleavy, G., Nikolaou, C. K., Nifakos, S., Atun, R., Law, G. C. Y., & Car, L. T. (2019). Mobile digital education for health professions: systematic review and meta-analysis by the digital health education collaboration. *Journal of Medical Internet Research*, *21*(2). https://doi.org/10.2196/12937

Elliot, L., Gehret, A., Valadez, M. S., Carpenter, R., & Bryant, L. (2020). Supporting Autonomous Learning Skills in Developmental Mathematics Courses with Asynchronous Online Resources. *American Behavioral Scientist*, *64*(7), 1012–1030. https://doi.org/10.1177/0002764220919149

Fabregas, E., Farias, G., Dormido-Canto, S., Guinaldo, M., Sánchez, J., & Bencomo, S. D. (2016). Platform for teaching mobile robotics. *Journal of Intelligent & Robotic Systems*, *81*(1), 131–143. https://doi.org/10.1007/s10846-015-0229-8

Fang, N., & Guo, Y. (2016). Interactive computer simulation and animation for improving student learning of particle kinetics. *Journal of Computer Assisted Learning*, *32*(5), 443–455. https://doi.org/10.1111/jcal.12145

Fidan, M., & Tuncel, M. (2019). Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education. *Computers & Education*, *142*, 103635. https://doi.org/10.1016/j.compedu.2019.103635

Flores-Vivar, J. M., & García-Peñalvo, F. J. (2023). Reflexiones sobre la ética, potencialidades y retos de la Inteligencia Artificial en el marco de la Educación de Calidad (ODS4). *Comunicar*, *31*(74). https://doi.org/10.3916/C74-2023-03

Gao, P., Li, J., & Liu, S. (2021). An Introduction to Key Technology in Artificial Intelligence and big Data Driven e-Learning and e-Education. *Mobile Networks and Applications*, *26*(5), 2123–2126. https://doi.org/10.1007/s11036-021-01777-7

Guilherme, A. (2017). AI and education: the importance of teacher and student relations. *AI & Society*, *34*(1), 47–54. https://doi.org/10.1007/s00146-017-0693-8

Halili, S. H. (2019). Technological advancements in education 4.0. *The Online Journal of Distance Education and E-Learning*, *7*, 63–69.

Han, J., Zhao, W., Jiang, Q., Oubibi, M., & Hu, X. (2019). Intelligent Tutoring System Trends 2006-2018: A Literature Review. *2019 Eighth International Conference on Educational Innovation through Technology (EITT)* (pp. 153–159). IEEE. https://doi.org/10.1109/eitt.2019.00037

Harrison, N. (1986). Patterns of participation in higher education for care-experienced students in England: why has there not been more progress? *Studies in Higher Education*, *45*(9), 1986–2000. https://doi.org/10.1080/03075079.2019.1582014

Hooshyar, D., Yousefi, M., & Lim, H. (2019). A systematic review of data-driven approaches in player modeling of educational games. *Artificial Intelligence Review*, *52*(3), 1997–2017. https://doi.org/10.1007/s10462-017-9609-8

Hoplock, L. B., Lobchuk, M. M., & Lemoine, J. (2020). Perceptions of an evidence-based empathy mobile app in post-secondary education. *Education and Information Technologies*, *26*, 1273–1292. https://doi.org/10.1007/s10639-020-10311-3

Ibáñez, M. B., Serio, A. D., Villarán, D., & Kloos, C. D. (2014). Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness. *Computers & Education*, *71*, 1–13. https://doi.org/10.1016/j.compedu.2013.09.004

Jawaid, I., Javed, M. Y., Jaffery, M. H., Akram, A., Safder, U., & Hassan, S. (2020). Robotic system education for young children by collaborative-project-based learning. *Computer Applications in Engineering Education*, *28*(1), 178–192. https://doi.org/10.1002/cae.22184

Jee, C. (2019). *Best chatbot building platforms.* Techworld. Retrieved from https://bit.ly/2Ate94F

Jiménez, E., Bravo, E., & Bacca, E. (2010). Tool for experimenting with concepts of mobile robotics as applied to children´s education. *IEEE Transactions on Education*, *53*(1), 88–95. https://

doi.org/10.1109/TE.2009.2024689

Jiménez-Hernández, E. M., Oktaba, H., Díaz-Barriga, F., & Piattini, M. (2020). Using web-based gamified software to learn Boolean algebra simplification in a blended learning setting. *Computer Applications in Engineering Education*, *28*(6), 1591–1611. https://doi.org/10.1002/cae.22335

Kavanagh, S., Luxton-Reilly, A., Wuensche, B., & Plimmer, B. (2017). A systematic review of Virtual Reality in education. *Themes in Science and Technology Education*, *10*(2), 85–119.

Lau, K. W., & Lee, P. Y. (2015). The use of virtual reality for creating unusual environmental stimulation to motivate students to explore creative ideas. *Interactive Learning Environments*, *23*(1), 3–18. https://doi.org/10.1080/10494820.2012.745426

Law, G. C., Dutt, A., & Neihart, M. (2019). Increasing intervention fidelity among special education teachers for autism intervention: A pilot study of utilizing a mobile-app-enabled training program. *Research in Autism Spectrum Disorders*, *67*, 101411. https://doi.org/10.1016/j.rasd.2019.101411

López-Rodríguez, M. I., & Barac, M. (2019). Valoración del alumnado sobre el uso de Clickers y vídeo tutoriales en educación superior. *Research in Education and Learning Innovation Archives*, *22*, 29–44. Retrieved from https://doi.org/10.7203/realia.22.14582 https://doi.org/10.7203/realia.22.14582

Madathil, K. C., Frady, K., Hartley, R., Bertrand, J., Alfred, M., & Gramopadhye, A. (2017). An empirical study investigating the effectiveness of integrating virtual reality-based case studies into an online asynchronous learning environment. *Computers in Education Journal*, *8*(3), 1–10.

Martínez, D. L., Karanik, M., Giovannini, M., & Pinto, N. (2015). Perfiles de Rendimiento Académico: Un Modelo basado en Minería de datos. *Campus Virtuales*, *4*(1), 12–30.

Masson, R., & Rennie, F. (2006). *ELearning. The key concepts*. Routledge.

McCormick, K. I., & Hall, J. A. (2022). Computational thinking learning experiences, outcomes, and research in preschool settings: a scoping review of literature. *Education and Information Technologies*, *27*, 1–36. https://doi.org/10.1007/s10639-021-10765-z

Merino-Armero, J. M., González-Calero, J. A., & Cozar-Gutierrez, R. (2022). Computational thinking in K-12 education. An insight through meta-analysis. *Journal of Research on Technology in Education*, *54*(3), 410–437. https://doi.org/10.1080/15391523.2020.1870250

Moreno, R. D. (2019). The arrival of artificial intelligence to education. *RITI Journal*, *7*(14), 260–270. https://doi.org/10.36825/RITI.07.14.022

Morris, S. B. (2008). Estimating effect sizes from pretest-posttest-control group designs. *Organizational Research Methods*, *11*, 364–386. https://doi.org/10.1177/1094428106291059

Neri, L., Noguez, J., Robledo-Rella, V., Escobar-Castillejos, D., & Gonzalez-Nucamendi, A. (2018). Teaching of Classical Mechanics Concepts using Visuo-haptic Simulators. *Educational Technology & Society*, *21*(2), 85–97.

Ocaña, Y., Valenzuela, L., & Garro, L. (2019). Artificial Intelligence and its Implications in Higher Education. *Propósito y Representaciones*, *7*(2), 536–568. http://doi.org/10.20511/pyr2019.v7n2.274

Olde, G. C. V.-D., De Jong, T., & Gijlers, H. (2013). Learning by Designing Instruction in the Context of Simulation-based Inquiry Learning. *Educational Technology & Society*, *16*(4), 47–58.

Page, M. J., Mckenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., & Moher, D. (2021). Declaración PRISMA 2020: una guía actualizada para la publicación de revisiones sistemáticas. *Revista Española de Cardiología*, *74*(9), 790–799. https://doi.org/10.1016/j.recesp.2021.06.016

Pareto, L. (2014). A teachable agent game engaging primary school children to learn arithmetic concepts and reasoning. *International Journal of Artificial Intelligence in Education*, *24*(3), 251–283. https://doi.org/10.1007/s40593-014-0018-8

Păsărelu, C. R., Andersson, G., & Dobrean, A. (2020). Attention-deficit/hyperactivity disorder mobile apps: A systematic review. *International Journal of Medical Informatics*, *138*. https://doi.org/10.1016/j.ijmedinf.2020.104133

Pellas, N., & Vosinakis, S. (2018). The effect of simulation games on learning computer programming: A comparative study on high school students' learning performance by assessing computational problem-solving strategies. *Education and Information Technologies*, *23*(3), 2423–2452. https://doi.org/10.1007/s10639-018-9724-4

Petko, D., Schmid, R., Müller, L., & Hielscher, M. (2019). Metapholio: A mobile app for supporting collaborative note taking and reflection in teacher education. *Technology, Knowledge and Learning*, *24*(4), 699–710. https://doi.org/10.1007/s10758-019-09398-6

Popenici, S. A. D., & Kerr, S. (2017). Exploring the impact of artificial intelligence on teaching and learning in higher education. *Technology Enhanced Learning*, *12*(1).).https://doi.org/10.1186/s41039-017-0062-8

Pyörälä, E., Mäenpää, S., Heinonen, L., Folger, D., Masalin, T., & Hervonen, H. (2019). The art of note taking with mobile devices in medical education. *BMC medical education*, *19*(1), 96. https://doi.org/10.1186/s12909-019-1529-7

Reister, M., & Blanchard, S. B. (2020). Tips and Tools for Implementing Progress Monitoring. *Kappa Delta Pi Record*, *56*(3), 128–134. https://doi.org/10.1080/00228958.2020.1770006

Riess, W., & Mischo, C. (2010). Promoting systems thinking through biology lessons. *International Journal of Science Education*, *32*(6), 705–725. https://doi.org/10.1080/09500690902769946

Roll, I., & Wylie, R. (2016). Evolution and revolution in artificial intelligence in education. *International Journal of Artificial Intelligence in Education*, *26*(2), 582–599. https://doi.org/10.1007/s40593-016-0110-3

Schachner, T., Keller, R., & Wangenheim, F. V. (2020). Artificial intelligence-based conversational agents for chronic conditions: systematic literature review. *Journal of Medical Internet Research*, *22*(9). https://doi.org/10.2196/20701

Shegog, R., Lazarus, M. M., Murray, N. G., Diamond, P. M., Sessions, N., & Zsigmond, E. (2012). Virtual transgenics: Using a molecular biology simulation to impact student academic achievement and attitudes. *Research in Science Education*, *42*(5), 875–890. https://doi.org/10.1007/s11165-011-9216-7

Singer-Brodowski, M., Brock, A., Etzkorn, N., & Otte, I. (2019). Monitoring of education for sustainable development in Germany-insights from early childhood education, school and higher education. *Environmental Education Research*, *25*(4), 492–507. .https://doi.org/10.1080/13504622.2018.1440380

Song, P., & Wang, X. (2020). A bibliometric analysis of worldwide educational artificial intelligence research development in recent twenty years. *Asia Pacific Education Review*, *21*(3), 473–486. https://doi.org/10.1007/s12564-020-09640-2

Stieff, M. (2011). Improving representational competence using molecular simulations embedded in inquiry activities. *Journal of Research in Science Teaching*, *48*(10), 1137–1158. https://doi.org/10.1002/tea.20438

Sun, L., Guo, Z., & Hu, L. (2021). Educational games promote the development of students' computational thinking: a meta-analytic review. *Interactive Learning Environments*, 1–15. https://doi.org/10.1080/10494820.2021.1931891

Tatli, Z., & Ayas, A. (2013). Effect of a Virtual Chemistry Laboratory on Students' Achievement. *Educational Technology & Society*, *16*(1), 159–170.

Tondeur, J., Roblin, N. P., Van Braak, J., Voogt, J., & Prestridge, S. (2017). Preparing beginning teachers for technology integration in education: Ready for take-off? *Technology, Pedagogy and Education*, *26*(2), 157–177. https://doi.org/10.1080/1475939X.2016.1193556

UNESCO. (2019). *The Sustainable Development Goals Report.* Retrieved from https://bit.ly/34nbq60

UNESCO. (2021). *International Forum on AI and the futures of education developing competencies for the AI era.* Retrieved from https://bit.ly/3zoB6AS

Veredas, F. J., Ruiz-Bandera, E., Villa-Estrada, F., Rufino-González, J. F., & Morente, L. (2014). A web-based e-learning application for wound diagnosis and treatment. *Computer Methods and Programs in Biomedicine*, *116*(3), 236–248. https://doi.org/10.1016/j.cmpb.2014.06.005

Vesisenaho, M., Juntunen, M., Häkkinen, P., Pöysä-Tarhonen, J., Fagerlund, J., Miakush, I., & Parviainen, T. (2019). Virtual Reality in Education: Focus on the Role of Emotions and Physiological Reactivity. *Journal of Virtual Worlds Research*, *12*(1). https://doi.org/10.4101/jvwr.v12i1.7329

Viechtbauer, W. (2010). Conducting Meta-Analyses in R with the metafor Package. *Journal of Statistical Software*, *36*(3), 1–48. https://doi.org/10.18637/jss.v036.i03

Vilkova, K., & Shcheglova, I. (2020). Deconstructing self-regulated learning in MOOCs: In search of help-seeking mechanisms. *Education and Information Technologies*, *26*, 17–33. https://doi.org/10.1007/s10639-020-10244-x

Vlachopoulos, D., & Makri, A. (2017). The effect of games and simulations on higher education: a systematic literature review. *International Journal of Educational Technology in Higher Education*, *14*(1), 22. https://doi.org/10.1186/s41239-017-0062-1

Walker, E., Rummel, N., & Koedinger, K. R. (2014). Adaptive intelligent support to improve peer tutoring in algebra. *International Journal of Artificial Intelligence in Education*, *24*(1), 33–61. https://doi.org/10.1007/s40593-013-0001-9

Wilkie, B., & Liefeith, A. (2020). Student experiences of live synchronised video feedback in formative assessment. *Teaching in Higher Education*, *27*(3), 403–416. https://doi.org/10.1080/13562517.2020.1725879

Wirjawan, J. V. D., Pratama, D., Pratidhina, E., Wijaya, A., Untung, B., & Herwinarso. (2020). Development of Smartphone App as Media to Learn Impulse-Momentum Topics for High School Students. *International Journal of Instruction*, *13*(3), 17–30. https://doi.org/10.29333/iji.2020.1332a

Yang, Y., Zhuang, Y., & Pan, Y. (2021). Multiple knowledge representation for big data artificial intelligence: framework, applications, and case studies. *Frontiers of Information Technology & Electronic Engineering*, *22*(12), 1551–1558. https://doi.org/10.1631/FITEE.2100463

Yelamarthi, K., & Drake, E. (2014). A flipped first-year digital circuits course for engineering and technology students. *IEEE Transactions on Education*, *58*(3), 179–186. https://doi.org/10.1109/TE.2014.2356174

Zacharia, Z. C., & Olympiou, G. (2011). Physical versus virtual manipulative experimentation in physics learning. *Learning and Instruction*, *21*(3), 317–331. https://doi.org/10.1016/j.learninstruc.2010.03.001

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education-where are the educators? *International Journal of Educational Technology in Higher Education*, *16*(1), 39. https://doi.org/10.1186/s41239-019-0171-0

Zhai, X., Chu, X., Chai, C. S., Jong, M. S. Y., Istenic, A., Spector, M., … Y (2010). A Review of Artificial Intelligence (AI) in Education from. *Complexity*, *8812542*. https://doi.org/10.1155/2021/8812542